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Environmental Assessment

Waste Treatment Facility

OWMC

Ontario
Waste Management
Corporation

A provincial crown corporation.

OWMC TREATMENT FACILITY
PROCESS AREA REPORT
PHYSICAL/CHEMICAL TREATMENT

Prepared by
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Attention: Mr. R. V. Griffiths, P.Eng.
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Gentlemen:

OWMC Treatment Facility
Monenco Contract No.: MNC 8084-2

Process Area Report
Physical/Chemical Treatment

We are pleased to submit herewith the draft report entitled: Process Area Report - Physical/Chemical Treatment. The report describes the rationale for the selection of technologies including the conceptual design of the physical/chemical treatment plant of OWMC's proposed Facility for the treatment and disposal of liquid industrial and hazardous waste in Ontario.

We trust that this report meets the Corporation's requirements.

Yours very truly,

J. V. Fitzgerald, P.Eng.
Project Manager

DC/jj

TABLE OF CONTENTS

PAGE

TITLE PAGE
TABLE OF CONTENTS
EXECUTIVE SUMMARY i

CHAPTER 1 - INTRODUCTION 1

1.1 PURPOSE OF THE REPORT 1
1.2 PURPOSE OF THE PHYSICAL/CHEMICAL TREATMENT PROCESSES 3

CHAPTER 2 - BASIS FOR TECHNOLOGY SELECTION AND PROCESS DESIGN 5

2.1 INTRODUCTION 5
2.2 OWMC PHILOSOPHY 5
2.3 WASTE PROFILE 6
2.4 PREMISES 7
2.5 POSTULATES 10

CHAPTER 3 - TECHNOLOGY EVALUATION AND SELECTION 18

3.1 INTRODUCTION 18
3.2 METHODOLOGY 18
3.3 CRITERIA FOR TECHNOLOGY SELECTION 19
    3.3.1 PERFORMANCE 20
    3.3.2 SAFETY 23
    3.3.3 FLEXIBILITY 25
    3.3.4 RELIABILITY 26
    3.3.5 OPERATIONS 27
    3.3.6 COMMERCIAL AND ECONOMIC 29
    3.3.7 CANADIAN BENEFITS 30
    3.3.8 APPLICATION OF THE TECHNOLOGY EVALUATION CRITERIA 31

TABLE OF CONTENTS (CONT'D)

PAGE

3.4 LONG LIST OF AVAILABLE TREATMENT TECHNOLOGIES 34
3.5 SELECTION OF SHORT LIST OF POTENTIALLY SUITABLE TREATMENT TECHNOLOGIES 36
3.6 EVALUATION OF POTENTIALLY SUITABLE TREATMENT TECHNOLOGIES 45
  3.6.1 TREATMENT OBJECTIVES 46
3.7 SELECTION OF PREFERRED TREATMENT TECHNOLOGIES 58
  3.7.1 PRIMARY TREATMENT 59
  3.7.2 SECONDARY TREATMENT 65
  3.7.3 EFFLUENT POLISHING 98

CHAPTER 4 - SYSTEM DESIGN AND OPTIMIZATION 123

4.1 INTRODUCTION 123
4.2 DESCRIPTION OF SELECTED PHYSICAL/CHEMICAL TREATMENT SYSTEMS 123
  4.2.1 INORGANIC WASTE TREATMENT SYSTEM 124
  4.2.2 AQUEOUS ORGANIC WASTE TREATMENT SYSTEM 127
  4.2.3 MISCELLANEOUS WASTE TREATMENT SYSTEM 129
4.3 SYSTEM OPTIMIZATION 131
  4.3.1 EQUIPMENT SELECTION AND SIZING 131
  4.3.2 INORGANIC WASTE TREATMENT SYSTEM 142
  4.3.3 AQUEOUS ORGANIC TREATMENT SYSTEM 157
  4.3.4 MISCELLANEOUS TREATMENT SYSTEM 160
  4.4 PLANT OPERATION 163
  4.5 SYSTEM PERFORMANCE 176
  4.5.1 INTRODUCTION 176
  4.5.2 STATUS OF DATA 178
  4.5.3 REMOVAL OF INORGANICS 181
  4.5.4 REMOVAL OF ORGANICS 202
  4.5.5 EVAPORATOR EMISSIONS 209
  4.6 SUMMARY AND CONCLUSIONS 214

TABLE OF CONTENTS (CONT'D)

PAGE

REFERENCES 216

GLOSSARY OF TERMS 221

APPENDIX A TECHNOLOGY EVALUATION A-1

APPENDIX B ADDITIONAL TREATABILITY DATA B-1

APPENDIX C METHODOLOGY FOR EVAPORATOR EMISSIONS ESTIMATE C-1

LIST OF FIGURES

FIGURE 1 PHYSICAL/CHEMICAL TREATMENT SCHEMATIC DIAGRAM 125
FIGURE 2 PICTORIAL FLOW DIAGRAM PHYSICAL/CHEMICAL TREATMENT 132
FIGURE 3 SITE LAYOUT LF-9C 133
FIGURE 4 PHYSICAL/CHEMICAL STORAGE TANK AREA CONCEPTUAL EQUIPMENT LAYOUT - PLAN 134
FIGURE 5 PHYSICAL/CHEMICAL TREATMENT PLANT CONCEPTUAL EQUIPMENT LAYOUT - GROUND FLOOR PLAN 135
FIGURE 6 PHYSICAL/CHEMICAL TREATMENT PLANT CONCEPTUAL EQUIPMENT LAYOUT - MEZZANINE FLOOR PLAN 136
FIGURE 7 PHYSICAL/CHEMICAL TREATMENT PLANT CONCEPTUAL EQUIPMENT LAYOUT PLAN - SECOND FLOOR 137
FIGURE 8 PHYSICAL/CHEMICAL TREATMENT PLANT CONCEPTUAL EQUIPMENT LAYOUT - SECTIONS 138
FIGURE 9 PHYSICAL/CHEMICAL TREATMENT PLANT OPERATING PHILOSOPHY SCHEMATIC 164

TABLE OF CONTENTS (CONT'D)

PAGE

LIST OF TABLES

TABLE 1 CANDIDATE WASTES FOR PHYSICAL/CHEMICAL TREATMENT 8
TABLE 2 SUMMARY OF WASTES EXPECTED TO REQUIRE PHYSICAL/CHEMICAL TREATMENT 12
TABLE 3 SUMMARY OF ALTERNATIVE PHYSICAL/CHEMICAL TREATMENT METHODS 54
TABLE 4 OXIDATION OF CYANIDE WASTEWATERS - ACHIEVABLE TREATMENT LEVELS 67
TABLE 5 ELECTROLYTIC DECOMPOSITON OF CYANIDE WASTE 68
TABLE 6 SUMMARY OF TREATMENT LEVELS REPORTED FOR HEXAVALENT CHROMIUM WASTES 80
TABLE 7 MINIMUM CONCENTRATIONS ATTAINABLE FOR KEY PARAMETERS IN TREATED EFFLUENT FROM THE PHYSICAL/CHEMICAL PLANT 182
TABLE 8 SUMMARY OF TREATMENT TECHNOLOGY FOR MERCURY 186
TABLE 9 POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR MERCURY 187
TABLE 10 PRECIPITATION TREATMENT FOR MERCURY 188
TABLE 11 ALUM AND IRON COAGULATION TREATMENT FOR MERCURY 188
TABLE 12 ACTIVATED CARBON TREATMENT FOR MERCURY 189
TABLE 13 REVERSE OSMOSIS TREATMENT FOR MERCURY 189
TABLE 14 SUMMARY OF EFFLUENT COPPER CONCENTRATIONS AFTER PRECIPITATION TREATMENT 192
TABLE 15 POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR COPPER 193
TABLE 16 TREATMENT OF COPPER WASTEWATER 194
TABLE 17 TREATABILITY OF COPPER BY ACTIVATED CARBON 194
TABLE 18 TREATABILITY OF COPPER BY REVERSE OSMOSIS 195
TABLE 19 TREATABILITY OF COPPER BY REVERSE OSMOSIS 196

TABLE OF CONTENTS (CONT'D)

PAGE

LIST OF TABLES (CONT'D)

TABLE 20 POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR PHENOL 198
TABLE 21 REMOVAL OF PHENOL BY ACTIVATED CARBON 199
TABLE 22 REMOVAL OF PHENOL BY ACTIVATED CARBON 199
TABLE 23 PERFORMANCE OF BIOLOGICAL SYSTEMS IN THE TREATMENT OF PHENOLIC WASTES 200
TABLE 24 REMOVAL OF PHENOL BY REVERSE OSMOSIS 201
TABLE 25 ESTIMATED EVAPORATOR EMISSIONS 210

APPENDIX A

TABLE A-1 COMPARISON OF OXIDATION PROCESSES A-2
TABLE A-2 COMPARISON OF REDUCTION PROCESSES A-11
TABLE A-3 COMPARISON OF SECONDARY PHASE SEPARATION (FOR SOLIDS/LIQUID SEPARATION) A-19
TABLE A-4 COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES (FOR OIL/WATER SEPARATION) A-23
TABLE A-5 COMPARISON OF SLUDGE DEWATERING PROCESSES A-27
TABLE A-6 COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL SUSPENDED SOLIDS AND IMMISCIBLE ORGANICS A-31
TABLE A-7 COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS A-35
TABLE A-8 COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS A-41

APPENDIX B

TABLE B-1 CHEMICAL TREATABILITY SUMMARY B-1

EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

This report describes the rationale for the selection of physical/chemical treatment technologies included in the conceptual design of OWMC's proposed Facility for disposing of liquid industrial wastes and hazardous wastes.

The background and rationale for including physical/chemical treatment processes in the design of OWMC's facility has been presented in earlier reports by Proctor & Redfern[1] and OWMC[2,3]. The choice of rotary kiln incineration, physical/chemical treatment, solidification and an engineered landfill as the four major components of the Facility was subsequently confirmed by Arthur D. Little of Canada Limited in their report entitled "Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario" - July 1985 (Ref: A.D. Little[4]).

This report describes the alternative physical, chemical and biological treatment technologies available, the methodology used to compare and evaluate them and the results of the technology evaluation process. The report also describes how the selected physical/chemical treatment technologies have been combined into treatment systems and outlines how these treatment systems have been optimized to maximize their performance, safety, flexibility and reliability.

This process area report on the physical/chemical treatment plant is one of five such reports which together cover all areas of the proposed OWMC treatment facility. Process area reports for the incinerator, solidification plant, landfill and general facilities are contained in separate documents (Refs: Monenco Limited[6,7,8,9]). These reports provide additional technical backup data and information in support of the system design and operating descriptions presented in the Facility Description (Ref: Monenco Limited[5]).

This report was prepared for OWMC by Monenco Limited who are also responsible for the conceptual engineering of the overall Facility. In addition, the technical expertise of Hessische Industriemüll GmbH (HIM), Frankfurt, West Germany is recognized for their contribution in reviewing the design and operating philosophy of the physical/chemical treatment processes.

SCOPE AND METHOD

A systematic approach was used to evaluate and select the preferred combination of physical/chemical treatment technologies best suited for OWMC's treatment facility using criteria which emphasize environmental factors. The selected physical/chemical treatment technologies were then combined into treatment process systems designed to ensure that OWMC's goals of minimizing risk to human health, impact on the environment and cost, are achieved in a satisfactory manner.

The following points summarize the approach and methodology employed:

- Establish the major treatment objectives and key treatment philosophies for the proposed physical/chemical treatment facility.
- Establish criteria for technology selection.
- Prepare a "long list" of possible physical/chemical technologies.
- Establish a "short list" of potentially suitable technologies and alternatives to these technologies.

- Define specific treatment requirements for each stage of physical/chemical treatment and list technologies which are capable of meeting these objectives.

- Evaluate and rank the relative suitability of each technology according to the established criteria and select one or more preferred technologies for inclusion in the conceputal process design.

- Design and optimize the resulting physical/chemical treatment system to meet the treatment objectives and philosophies of OWMC.

PREMISES AND POSTULATES

OWMC has developed the following basic planning principles and guidelines which are central to technology selection and process design in all areas of the proposed Facility including the physical/chemical treatment plant.

- Wastes must undergo treatment to the fullest extent possible using best available proven technology, prior to the safe disposal of the remaining treated residues.

- It is the Corporation's goal to:
  - minimize risk to human health,
  - minimize environmental impacts and
  - minimize financial costs to OWMC and the people of Ontario.

The following additional premises provided by OWMC have been used as starting points for technology selection and process design of the physical/chemical treatment plant.

- The physical/chemical treatment plant will be designed to treat special wastes which are primarily inorganic in nature. All organic wastes which are sent to OWMC's facility for treatment will be destroyed in a rotary kiln incinerator. Solid and liquid residues from the physical/chemical treatment plant will be further treated in a solidification plant prior to being disposed of in an engineered landfill.

o OWMC's preference is to discharge excess treated effluent from the Facility by evaporation. Other effluent disposal options considered by the Corporation were:
  - total solidification of all treated effluents prior to disposal in the engineered landfill,
  - discharging treated effluents by pipeline or truck to a receiving body of water or sewer system, and
  - deep well injection.

o All of the treatment and disposal components, including support facilities, will be located on one site.

o The physical/chemical treatment plant will be designed for an initial nominal capacity of 120 000 t/a of inorganic special wastes based on a total Facility capacity of 150 000 t/a plus an allowance for wastes generated on site.

o The physical/chemical treatment plant will be designed to treat special wastes at a rate of 50 000 t/a based on an 8 hour per day operation, 5 days per week, 50 weeks per year.

o Additional hours will be operated as required to achieve sufficient throughput capacity to handle up to 120 000 t/a of inorganic special wastes.

o The ultimate design capacity of the physical/chemical treatment plant will be 240 000 t/a based on a total Facility capacity of 300 000 t/a.

- Space will be provided on the Facility layout to enable the physical/chemical storage and treatment facilities to be expanded to achieve the ultimate design capacity of 240 000 t/a.

- The arrival of wastes at the Facility will be scheduled in advance.

- The bulk tanker loads of wastes delivered to the Facility are expected to range in size from 10t to 40t with an average of approximately 15t.

- The types and quantities of wastes which are expected to require treatment in the physical/chemical plant have been determined taking into account waste data provided by OWMC.

- Due to expected variations in the types and quantities of wastes requiring treatment at OWMC's Facility, it is necessary that the physical/chemical treatment process design incorporate features such as:
  - maximum flexibility,
  - future expansion capability and
  - reserve storage and treatment capacity.

Postulates are assumptions or hypotheses which are basic to the approach used to evaluate alternatives and arrive at an optimum process design. The key assumptions, treatment objectives and treatment philosophies which have influenced technology evaluations and process design of the physical/chemical plant are summarized by the following points:

- The physical/chemical treatment processes will be designed to achieve the following treatment objectives:
  - To treat incoming special waste of a primarily inorganic nature to a quality suitable for:
    - further processing by solidification,
    - further processing by incineration,

    - reuse for process water requirements within the Facility such as make up water for the incinerator flue gas cleaning system, wash water or reagent make up, and
    - evaporation with steam discharge to atmosphere.
  - To treat selected batches of aqueous organic waste.
  - To treat miscellaneous wastes including wash water and contaminated storm water generated within the Facility to the same quality objectives as the special waste.
  - To ensure that:
    - treatment operations can be carried out safely and that,
    - no liquid effluents will be discharged or evaporated to atmosphere before being tested

- o Technology selection for the physical/chemical treatment plant will be directed toward selecting the combination of physical/ chemical treatment processes which are best suited to this particular application, recognizing that no single physical/chemical process is capable of fulfilling all of the required treatment functions.

- o The physical/chemical treatment processes will be selected and arranged to achieve a stepwise reduction in dissolved and suspended contaminants from untreated waste to final treated effluent. Treatment will proceed through primary treatment (where required), secondary treatment and effluent polishing. This approach will ensure that all wastes undergo the best possible treatment.

- o Alternative physical/chemical treatment processes will be grouped and evaluated based on their relative abilities to fulfill specific treatment objectives at each stage of the treatment process. This approach ensures that alternative technologies are evaluated and compared only for treatment functions which they are best suited to perform.

- The physical/chemical plant will treat all special wastes in a batchwise fashion. Individual batches will not be mixed unless mixing has been shown (in the laboratory) to be safe and to enhance treatability. This mode of operation has been adopted to maximize the control and effectiveness of each stage of the treatment process. Processes must therefore permit short start-up and shut-down times and enable individual batches to be treated separately with minimal cross contamination or intermixing.

- Where possible, one waste will be used to treat another to minimize the use of reagents.

- A range of environmental, safety and engineering-related criteria were used as a basis for evaluating and comparing alternative physical/ chemical treatment technologies. Emphasis was placed on the environmental aspects of four such criteria: performance, safety, flexibility and reliability to ensure that the treatment processes selected represent best available proven technology.

- Technology selection and process design for the physical/chemical plant will not be a one time effort but an evolutionary and ongoing process. Changes and improvements will be made as required throughout the life of the plant to adapt to changing waste characteristics and technological improvements and to continuously improve the efficiency of the system for achieving the best possible treatment.

- Laboratory scale treatability tests will be carried out on wastes prior to blending and/or treatment in order to:
  - ensure that the treatment efficiency will not be adversely affected by blending certain wastes prior to or during treatment,
  - select the optimum treatment steps and processing sequences,
  - determine optimum process conditions, and
  - verify the quality of the treated effluent.

- Batches of aqueous organic waste which are not amenable to physical/chemical treatment will be incinerated. Batches of inorganic waste which contain unacceptable concentrations of organics after treatment will either be retreated or incinerated.

- Batches of inorganic waste which contain very high concentrations of dissolved salts after treatment will either be solidified directly or concentrated by evaporation to reduce the volume requiring solidification and landfilling.

- The physical/chemical treatment plant will be designed to process 50 000 t/a of inorganic waste when operating 8 hours/day, five days/week, 50 weeks/year. This will result in a nominal capacity of 200 t/8 hours. However, the physical/chemical treatment system will be sized to handle 320 t/8 hours in order to provide an allowance for retreating batches which fail to meet the treatment objective and to accommodate additional waste quantities generated on-site. These on-site generated wastes include equipment flushing water, truck wash water, boiler blowdown, laboratory waste water, ventilation air scrubber blowdown, dilution water used to slurry non-pumpable wastes requiring treatment, and water associated with reagent additions.

- The physical/chemical treatment plant will be designed to handle and treat special wastes in solid or liquid form or in mixtures of solids and liquids ranging from slurries to pastes.

- The physical/chemical treatment system will be capable of removing both immiscible and dissolved organic contaminants in addition to its primary role in removing and/or detoxifying inorganic contaminants.

- The physical/chemical treatment system will be designed to reduce the water content of some aqueous organic wastes prior to incineration of the recovered organics in order to minimize the quantities of low heating value wastes being fed to the incinerator. However, no provision will be made to recover specific organic or inorganic chemicals for recycle or reuse outside the Facility for the following reasons:

- The existing waste profile information has not identified any wastes, either organic or inorganic, which stand out as particularly suitable candidates for recovery and reuse.
- Since the exact nature and quantities of the various waste types which will be sent to OWMC's Facility for treatment will not be known until after start up, it is more practical that specific opportunities for waste recovery and reuse outside the Facility be identified and evaluated after the Facility has commenced operation.

- All potentially contaminated surface drainage from the landfill area, and all surface drainage from the central operating area will be collected and its quality checked before being discharged from the site. The quality of the landfill leachate will also be monitored on a regular basis. These "miscellaneous wastes" will be treated in the physical/chemical plant if required.

- Batches of treated effluent which are not suitable for reuse or final discharge by evaporation will either be retreated in the physical/chemical plant or directed to one of the other process areas for treatment. If the residual contaminants are inorganic in nature, these batches will be solidified and placed in the engineered landfill. If the residual contaminants are organic in nature, these batches will be incinerated.

STATUS OF DATA

The waste profile developed by OWMC is considered to be typical. However, wide variations are expected to occur from batch to batch. Changes are also expected to occur over the operating life of the Facility. These factors have been accounted for in the selection of technologies and in the design and optimization of the physical/chemical treatment system.

Data and information from published literature reviews and evaluations (Proctor & Redfern[1], USEPA[10], USEPA[11] and Arthur D. Little[12],) have been used as a starting point along with additional published information from other sources, in-house experience and engineering judgement as a basis for rationalizing the selection and arrangement of physical/chemical treatment process technologies.

A logical and quantitative methodology has been adopted to evaluate alternative physical/chemical treatment technologies. This methodology has been adopted to assist in the technology selection process to enable all of the technology selection criteria to be accounted for in a rational manner during the evaluation process while at the same time ensuring that important selection criteria are properly accounted for. This methodology has not however eliminated the need for qualitative evaluation and judgement in the selection of the preferred technologies.

The performance of the resulting physical/chemical treatment system has been evaluated from an assessment of treatability data available from published sources along with additional data on the performance of the primary and secondary treatment steps from the Hessische Industriemull GmbH (HIM) facility in Frankfurt, West Germany.

Technical reviews of the design and operating philosophies of the physical/chemical treatment system have also been provided by HIM of Frankfurt, West Germany.

MAIN FINDINGS

The physical/chemical treatment plant will incorporate three process treatment systems corresponding to the three categories of waste which are expected to require physical/chemical treatment.

- An inorganic treatment system, which is designed to treat inorganic special wastes delivered to the facility plus inorganic wastes generated on site such as ventilation air scrubber blowdown, truck wash water and flushing water.
- An aqueous organic treatment system, which is designed to treat selected aqueous organic wastes plus dilute organic containing wastes generated on site such as truck wash water and flush water containing organic contaminants.
- A miscellaneous treatment system, which is designed to treat landfill leachate and contaminated surface drainage.

The inorganic treatment system will consist of the following unit processes:

- Primary treatment
  - phase separation
  - dissolution/slurrying
  - blending

- Secondary treatment
  - oxidation/reduction
  - neutralization/precipitation
  - coagulation/sedimentation
  - sludge dewatering

- Intermediate storage

- Effluent polishing
  - granular media filtration
  - activated carbon adsorption
  - reverse osmosis

- Final treated effluent storage

- Evaporation

Evaporation will serve a dual role in the physical/chemical treatment system as a treatment step for removing high (>4 % by weight) total dissolved solids concentrations from partially treated effluents prior to reuse. In addition, evaporation is the preferred means of discharging the excess treated effluent which can not be reused on site.

The aqueous organic treatment system will consist of the following unit processes:

- Primary treatment
  - phase separation
  - blending
- Secondary treatment
  - emulsion breaking
  - centrifugation
  - dissolved air flotation
  - activated carbon adsorption
- Intermediate storage

From intermediate storage, batches of partially treated aqueous organic wastes will receive additional secondary and/or effluent polishing treatment in the inorganic treatment system.

The miscellaneous treatment system will consist of the following unit processes:

- Primary/secondary treatment
  - equalization
  - neutralization/precipitation
  - flocculation/sedimentation
  - sludge dewatering

- Effluent polishing
  - granular media filtration
  - activated carbon adsorption
  - reverse osmosis

- Final treated effluent storage
- Evaporation

The physical/chemical plant incorporates the best available proven treatment technologies. The system design and operating philosophies have been optimized to provide a high degree of performance, safety, flexibility and reliability in the following manner:

- Provision has been made for treatability testing to be carried out on actual waste samples prior to full scale treatment to establish optimum treatment formulations and verify that an acceptable effluent quality can be achieved.

- Maximum flexibility has been incorporated in the system design to enable the optimum treatment processing sequences to be selected for each batch of waste being treated.

- Provision has been made in the building layout to accommodate additional physical, chemical or biological treatment processes as required in the future to respond to changing waste profiles, improve the efficiency of the treatment process and take advantage of future improvements in treatment technology.

- Provision has been made for carrying out quality control checks, during and after treatment, to verify that the systems are performing as expected.

- Provision has been made for retreating batches of waste which fail to meet the treatment objective.

- Provision has been made for batches of treated effluent which are unsuitable for reuse or discharge to be either incinerated, if the residual contaminants are organic in nature, or solidified, if the residual contaminants are inorganic in nature.

- Similarly, treated residues which are not suitable for direct solidification due to their organic content will be subjected to incineration for the destruction of organics.

It should be noted that work is presently being conducted by other OWMC consultants to address compliance of Facility emissions with Ontario regulations and to determine health risks resulting from such emissions. This work is ongoing and being undertaken by Ontario Research Foundation and Environ Corporation respectively, and will be available prior to the formal environmental assessment submission.

The results obtained to date from the work being conducted by Environ Corporation and Ontario Research Corporation indicate that OWMC's physical/chemical treatment plant will treat wastes in a highly effective manner which will thereby minimize risk to human health and impact on the environment.

CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF THE REPORT

This report describes the rationale for the selection and optimization of technologies for inclusion in the conceptual design of the physical/chemical treatment plant of OWMC's proposed Facility for the treatment of liquid industrial wastes and hazardous wastes. The report describes the alternative technologies considered, the methodology used to compare and and evaluate them and the results of the technology selection process. The report also describes how the selected physical/chemical treatment technologies have been combined into treatment process systems and outlines how the process design has been optimized to maximize the performance, safety, flexibility and reliability of the physical/chemical treatment operation at minimum cost.

The background and rationale for including physical/chemical treatment processes in the design of OWMC's Facility has been presented in earlier reports by Proctor & Redfern[1], OWMC[2,3]. The choice of rotary kiln incineration, physical chemical treatment, solidification and an engineered landfill as the four major components of the Facility was subsequently confirmed by A. D. Little of Canada Limited[4] in their report entitled "Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario" - July 1985. (Ref: A.D. Little[4]).

This process area report on the physical/chemical treatment plant is one of five such reports which together cover all areas of OWMC's proposed treatment Facility. These reports provide additional technical data and information in support of the system design and operating description presented in the Facility Description (Ref: Monenco Limited[5]). Process area reports for Incineration, Solidification, Landfill and General Facilities are contained in separate documents (Refs: Monenco Limited[6,7,8,9]).

Several earlier published reports such as Arthur D. Little[12], USEPA[10,11] and Proctor & Redfern[1] have summarized the results of extensive literature reviews and evaluations on alternative technologies which can and have been used for the treatment of hazardous industrial wastes. Some of the descriptive information from Proctor & Redfern[1] and Arthur D. Little[12] has been used in this report for completeness in order to provide the reader with a brief outline of the basic principles of operation of each technology. However, the purpose of this report is not simply to reiterate the information presented in these earlier reports but to use such information as a starting point along with additional published information from other sources, engineering experience and judgement as a basis for rationalizing the selection and arrangement of physical/chemical treatment process technologies which are best suited to the particular requirements of OWMC's treatment Facility.

Chapter 2 of the report summarizes the origins, policies and objectives of OWMC, the wastes that are expected to be treated in the physical/chemical plant and the basic assumptions (premises and postulates) which have governed the technology evaluation and system design of the physical/chemical treatment processes. Chapter 3 then presents the results and conclusions of the technology evaluation process including reasons for either accepting or rejecting each of the alternative generic treatment processes. Chapter 4 of the report describes the manner in which the selected treatment technologies will be assembled into systems for treating inorganic, aqueous/organic and miscellaneous wastes which are expected to require physical/chemical treatment. Chapter 4 also outlines the manner in which the design and operation of these systems has been optimized to ensure that effective treatment can be achieved on a consistent basis.

This report was prepared for OWMC by Monenco Limited, who are also responsible for conceptual engineering of the overall treatment Facility. In addition, the technical expertise of Hessische Industriemüll GmbH (HIM), Frankfurt, West Germany is recognized for their contribution in reviewing the design and operating philosophies of the physical/chemical treatment processes.

1.2 PURPOSE OF THE PHYSICAL/CHEMICAL TREATMENT PROCESSES

Inorganic wastes which are delivered to the proposed OWMC Facility for treatment and disposal will be treated by physical/chemical processes. Organic wastes which are delivered to the Facility will be destroyed by high temperature incineration.

The physical/chemical treatment processes are designed to chemically stabilize, detoxify and/or concentrate all inorganic contaminated wastes which are either delivered to the Facility for treatment or produced on site. It is expected that treated inorganic residues will also be delivered to the OWMC Treatment Facility for disposal. In some cases residues will have been adequately stabilized, detoxified and/or concentrated prior to their arrival at the Facility. These wastes will be solidified prior to being disposed of in an engineered landfill.

The physical/chemical treatment system is designed to treat any contaminated surface drainages or landfill leachates.

The physical/chemical treatment plant is also designed to treat selected aqueous organic wastes which contain low concentrations of organic contaminants.

Treated effluents from the physical/chemical treatment plant will be reused on site to the maximum extent possible. Evaporation is the preferred method for discharging excess treated effluent from the Facility. Organic contaminants which are recovered from the aqueous organic wastes will be incinerated. The treated inorganic residues from the physical/chemical treatment process will be solidified to produce a material which is both physically and chemically stable. This solidified material will be disposed of in the engineered landfill.

CHAPTER 2

BASIS FOR TECHNOLOGY SELECTION AND PROCESS DESIGN

2.1 INTRODUCTION

An important aspect of the evaluation and selection of appropriate physical/chemical treatment technologies for OWMC's treatment Facility is to define the framework within which the selected treatment processes will be expected to operate. This framework is defined by:

- OWMC's philosophies,
- the type and quantities of wastes which are likely to require treatment in the physical/chemical plant,
- the particular treatment objectives, philosophies and assumptions (premises and postulates) which have been applied to the design of the physical/chemical plant and
- the capabilities of the physical/chemical plant in relation to those of the other major process areas (i.e. incineration and solidification areas) within OWMC's Facility.

2.2 OWMC PHILOSOPHY

OWMC has developed several basic planning principles and guidelines which are central to technology selection and process design in all areas of the proposed treatment Facility including the physical/chemical processes. The following points summarize these key treatment philosophies.

- OWMC's primary responsibility is to establish and operate a liquid industrial waste and hazardous waste management system in Ontario. It has no responsibility for managing municipal solid waste or radioactive waste, nor is it a regulator of other industrial waste management systems (OWMC[3]).

- OWMC Facilities, no matter how large or small they ultimately may be, must be designed to handle all types of special waste. This full service capability is inherent in OWMC's responsibility as a public agency.

- Wastes must undergo the best possible treatment, using proven technologies, prior to the safe disposal of the remaining treated residues.

- It is the Corporation's goal to:

  - minimize risk to human health,
  - minimize environmental impacts and
  - minimize financial costs to OWMC and the people of Ontario.

2.3 WASTE PROFILE

OWMC commissioned a waste quantities study in Phase 1 of the Facilities Development Process which proposed a classification of Ontario special waste and estimated the quantities of each (OWMC[2,3,13]). Additional work has subsequently been conducted to improve available data and to refine OWMC's assumptions on the quantities and characteristics of wastes it will be receiving for treatment and disposal. These most recent data have been used as a basis for ensuring that the physical/chemical treatment facility will have the necessary processes, capacity and flexibility to respond to the waste treatment and disposal needs of industries in Ontario.

Table 1 summarizes the waste classes and waste quantities which are likely candidates for physical/chemical treatment.

Conclusions drawn from the existing waste profile information have had an influence on the technology selection and process design of the physical/chemical treatment plant. These are summarized in Section 2.5 (pg.10). It is recognized that the nature and quantity of the various waste types which arrive at OWMC's Facility may differ from that presently envisaged and will likely continue to change throughout its operating life. The ability of the selected physical/chemical treatment systems to handle such variations was considered essential and is further discussed in Section 3.3.3 (pg. 25).

2.4 PREMISES

Premises are the information provided by OWMC or by other studies undertaken by the Corporation which have been taken as points of departure for new work. OWMC's basic planning principles and guidelines presented in Section 2.2. (p. 5) are premises which apply to the OWMC's Treatment Facility as a whole including the physical/chemical plant. The following additional premises have also been used as starting points for technology selection and process design in the physical/chemical plant.

- The physical/chemical treatment plant will be designed to treat special wastes which are primarily inorganic in nature. Organic wastes which are sent to OWMC's Facility for treatment will be burned in a rotary kiln incinerator. Solid and liquid residues from the physical/chemical treatment plant will be further treated in a solidification plant prior to being disposed of in an engineered landfill.

TABLE 1
CANDIDATE WASTES FOR PHYSICAL/CHEMICAL TREATMENT

OWMC CLASS		TYPICAL TOTAL QUANTITY EXPECTED AT OWMC FACILITY (t/a)	TYPICAL WASTE QUANTITIES TO:		
			ORGANIC	INORGANIC	
			INCINERATION (t/a)	PHYS/CHEM (t/a)	SOLIDIFICATION (t/a)
1	Organic Sludgesand Still Bottoms	11 050	9 580	**1 470**	0
2	Solvents and Organic Solutions	3 330	3 330	**0**	0
3	Oils and Greases	880	880	**0**	0
4	Oil/Water Mixtures	3 530	3 530	**0**	0
5	Organic and Oily Residues	6 030	3 790	**2 240**	0
6	Heavy Metal Solutions and Residuals	79 480	0	**66 055**	13 430
7	Miscellaneous Chemicals and Products	3 100	860	**2 240**	0
8	Paint and Organic Residuals	5 030	4 750	**280**	0
9	Aqueous Solutions and Organics	1 790	600	**1 190**	0
10	Anion Complexes	1 070	0	**1 070**	0
11	Sludges and Inorganic Residuals	32 030	0	**12 660**	19 370
12	Pesticide and Herbicide Waste	180	180	**0**	0
13	PCB Wastes	30	30	**0**	0
14	Clean Up Residuals	2 470	2 470	**0**	0
				87 200	32 800
	TOTALS	150 000	30 000	120 000	

Notes:

- Waste quantities are derived from OWMC Waste Profile Information (November, 1984) and are rounded off to the nearest 10 t/a.

- Aqueous/organic wastes from categories 4, 5, 7, 8 and 9 will be selected for physical/chemical treatment based on the following criteria:

  - The waste contains an immiscible organic phase which is amenable to separation by physical/chemical methods prior to incineration.
  - The recovered aqueous phase is amenable to further physical/chemical treatment to produce an effluent of acceptable quality.
  - The waste contains unacceptably high concentrations of heavy metals which are amenable to removal by physical/chemical methods prior to incineration.

  The suitability of aqueous/organic wastes for physical/chemical treatment will be determined in advance based on laboratory scale treatability data.

- OWMC's preference is to discharge excess treated effluent from the Facility by evaporation. Other effluent disposal options considered by the Corporation were:

  - total solidification of all treated effluents prior to disposal in the engineered landfill,
  - discharging treated effluents by pipeline or truck to a receiving body of water or sewer system, and
  - deep well injection.

- All of the treatment and disposal components, including support facilities, will be located on one site.

- The physical/chemical treatment plant will be designed for an initial nominal capacity of 120 000 t/a of inorganic special wastes based on a total Facility capacity of 150 000 t/a plus an allowance for waste generated on site.

- The physical/chemical treatment plant will be designed to treat special wastes at a rate of 50 000 t/a based on an 8 hour per day operation, 5 days per week, 50 weeks per year.

- Additional shifts will be operated as required to achieve sufficient throughput capacity to handle up to 120 000 t/a of inorganic special wastes.

- The ultimate design capacity of the physical/chemical treatment plant will be 240 000 t/a based on a total Facility capacity of 300 000 t/a.

- Space will be provided on the Facility layout to enable the physical/chemical storage and treatment facilities to be expanded to achieve the ultimate design capacity of 240 000 t/a.

- The arrival of wastes at the Facility will be scheduled in advance.

- o The bulk tanker loads of wastes delivered to the Facility are expected to range in size from 10t to 40t with an average of approximately 15t (OWMC[3]).

- o The types and quantities of special wastes which could require treatment in the physical/chemical plant have been obtained from OWMC's Waste Profile information.

- o The waste profile shown in bold face on Table 1 is typical of the types and quantities of waste the physical/chemical plant could receive. However, variations may result from:

  - industry's response to market demands and to financial constraints,
  - process and manufacturing changes, and
  - changes in Provincial waste regulations.

  On this basis it is important that the physical/chemical treatment process design incorporate features such as:

  - maximum flexibility,
  - future expansion capability and
  - reserve storage and treatment capacity.

2.5 POSTULATES

Postulates are assumptions or hypotheses which are basic to the approach used to evaluate alternatives and arrive at an optimum process design. The key assumptions, treatment objectives and treatment philosophies which have influenced technology evaluations and process design for the physical/chemical plant are summarized by the following points:

- o The physical/chemical treatment processes will be designed to achieve the following treatment objectives:

- To treat incoming special waste of a primarily inorganic nature to a quality suitable for:
    - further processing by solidification,
    - further processing by incineration,
    - reuse for process water requirements within the Facility such as make up water for the incinerator flue gas cleaning system, washwater or reagent make up, and
    - evaporation with steam discharge to atmosphere
- To treat selected batches of aqueous organic waste (refer to notes on p. 8).

- To treat miscellaneous wastes, including contaminated storm water generated within the Facility, to the same quality objectives as the special waste.
- To ensure that:
    - treatment operations can be carried out safely and that
    - no liquid effluents will be evaporated or discharged before being tested.

o The types and estimated quantities of inorganic, aqueous organic and miscellaneous wastes are summarized in Table 2.

o Technology selection for the physical/chemical treatment plant will be directed toward selecting a preferred combination of physical/chemical treatment processes which are best suited to this particular application recognizing that no single physical/chemical process is capable of fulfilling all of the required treatment functions.

o The physical/chemical treatment processes will be selected and arranged to achieve a stepwise reduction in dissolved and suspended contaminants from untreated waste to final treated effluent. Treatment will proceed through primary treatment (where required), secondary treatment and effluent polishing. This approach will ensure that all wastes undergo the best possible treatment.

TABLE 2
SUMMARY OF WASTES EXPECTED TO REQUIRE PHYSICAL/CHEMICAL TREATMENT

WASTE STREAM	DESCRIPTION	ESTIMATED WASTE QUANTITIES(1) (t/a)
INORGANIC WASTES		
o INORGANIC SPECIAL WASTES[2]	- pumpable acidic wastes	25 000
	- pumpable neutral and alkaline wastes	55 000
	- non-pumpable wastes requiring phys/chem treatment (See Note 1)	16 000
	Sub Total	96 000
o LABORATORY	- wastes resulting from laboratory analyses and treatability testing	See Note 3
o SCRUBBER BLOWDOWNS	- blowdown from ventilation air scrubbers in phys/chem, truck unloading, drum handling and truck wash areas	4 000
o INORGANIC TRUCK WASH WATER	- spent inorganic washwater from truck washing facility	3 800
o WATER TREATMENT WASTES	- wastes from raw water demineralizer and softener units plus boiler blowdown	6 000
o FLUSH WATER	- flushwater from inorganic bulk unloading area, drum handling area and process floor areas	14 000
	Total Inorganic Wastes	123 800
AQUEOUS ORGANIC WASTES		
o AQUEOUS/ORGANIC SPECIAL WASTES	- selected oil/water mixtures with high water content (see Table 1, Note 1, p. 8)	5 300
o INORGANIC SPECIAL WASTES	- inorganic wastes containing immiscible organics	12 500(4)
o FLUSH WATER	- flushwater from organic bulk unloading area, organic drum handling and organic process floor areas	1 500
o ORGANIC TRUCK WASH WATER	- spent organic washwater from truck washing facility	1 900
o CONTAMINATED SURFACE DRAINAGE	- contaminated storm drainage from within organic tank farm containment dykes	500
	Total Aqueous/Organic Wastes	21 700

TABLE 2
SUMMARY OF WASTES EXPECTED TO REQUIRE PHYSICAL/CHEMICAL TREATMENT

WASTE STREAM	DESCRIPTION	ESTIMATED WASTE QUANTITIES(6) (t/a)
MISCELLANEOUS WASTES		
o LANDFILL LEACHATE	- if treatment is required	22 000(5) (22 000)
o LANDFILL AREA SURFACE DRAINAGE	- if treatment is required	5 000 (20 000)
o POTENTIALLY CONTAMINATED SURFACE DRAINAGE	- drainage from the potentially contaminated surface drainage collection system on site (if contaminated)	5 000 (59 000)
o CLEAN SURFACE DRAINAGE	- drainage from the clean surface drainage collection system on site (if contaminated)	0 (57 000)
	Total Miscellaneous Wastes	32 000 (158 000)

Notes:

1. Includes 2 400 t/a of non pumpable waste plus an allowance of 13 600 t/a for slurry and/or dilution water.
2. From OWMC classes 6, 9 and 10 on Table 1 (p. 8).
3. Estimated quantity of 250 t/a has been included in total quantity of special wastes.
4. An allowance of 12 500 t/a has been made in the design capacity of the aqueous/organic treatment process train to pretreat inorganic "special" wastes which may contain immiscible organics.
5. Based on estimated flows after 20 years of landfill operation.
6. Estimated waste quantities are average values. Numbers in brackets represent estimated maximum quantities.

- Alternative physical/chemical treatment processes will be grouped and evaluated based on their relative abilities to fulfill specific treatment objectives at each stage of the treatment process. This approach ensures that alternative technologies are evaluated and compared only for treatment functions which they are best suited to perform.

- The physical/chemical plant will treat all special wastes in a batchwise fashion. Individual batches will not be mixed unless mixing has been shown (in the laboratory) to be safe and to enhance treatability. This mode of operation has been adopted to maximize control and effectiveness of each stage of the treatment process. Physical/chemical unit operations which require long start up and shutdown times or which must operate on a continuous basis were therefore considered to be less suitable for this particular application. Similarly, processes which do not permit individual batches to be treated separately with minimal cross contamination or intermixing were also considered to be less suitable for this application.

- A range of environmental, safety and engineering criteria were used as a basis for evaluating and comparing alternative physical/chemical treatment technologies. Emphasis was placed on the environmental aspects of four such criteria: performance, safety, flexibility and reliability to ensure that the treatment processes selected represent the best available proven technology in keeping with OWMC's objectives. These criteria reflect OWMC's principal goals to minimize risk to human health and minimize impacts on the environment.

- Technology selection and process design for the physical/chemical plant will not be a one time effort but an evolutionary and ongoing process. Changes and improvements will be made as required throughout the life of the plant to adapt to changing waste profiles and technological improvements and to continuously improve the efficiency of the system for achieving the best possible treatment.

- Laboratory scale treatability tests will be carried out on wastes prior to blending and/or treatment in order to:
  - ensure that the treatment efficiency will not be adversely affected by blending certain wastes prior to or during treatment,
  - select the optimum treatment steps and processing sequence,
  - determine optimum process conditions, and
  - verify the quality of the treated effluent.

- Physical/chemical treatment technologies which do not lend themselves to laboratory testing or are not able to produce the required results within a reasonable period of time were considered to be less suitable for this application.

- Batches of aqueous/organic waste which are not amenable to physical/chemical treatment will be incinerated. Batches of inorganic waste or treated residues which contain unacceptable concentrations of organics after treatment will either be retreated or incinerated.

- Batches of inorganic waste which contain very high concentrations of dissolved salts after treatment will either be solidified directly or concentrated by evaporation to reduce the volume requiring solidification and landfilling.

- The physical/chemical treatment plant will be designed to process 50 000 t/a of inorganic waste when operating 8 hours/day, five days/week, 50 weeks/year. This will result in a nominal capacity of 200 t/8 hours. However, the physical/chemical treatment system will be sized to handle 320 t/8 hours in order to provide an allowance for retreating batches which fail to meet the treatment objective and to accommodate additional waste quantities generated on-site. These on-site generated wastes include flush water, truck wash water, laboratory waste water, ventilation air scrubber blowdown, dilution water used to slurry non-pumpable wastes requiring treatment, and water associated with reagent additions as outlined on Table 2 (p. 12).

- The physical/chemical plant will be designed to handle and treat special wastes in solid or liquid form or in mixtures of solids and liquids ranging from slurries to pastes.

- The available waste profile information indicates that a portion of the "inorganic" wastes which are expected to require physical/chemical treatment could contain organics (up to 1 to 2% in some cases). Because the specific types and concentrations of organics likely to be present in these wastes is not known, it is necessary that the physical/chemical treatment system be capable of removing a range of both immiscible and dissolved organic contaminants in addition to its primary role in removing and/or detoxifying a wide range of inorganic contaminants.

- The waste profile data also indicates that the physical/chemical treatment methods could possibly be applied with some benefit to selected mixtures of aqueous wastes and immiscible organics from OWMC classes 1, 5, 7, 8 and 9 primarily as a means of upgrading the heating value of aqueous wastes which contain free or emulsified organics. Although the total quantity of these "aqueous/organic" wastes is likely to constitute only about 5 % by weight of the total waste profile, it has been concluded that the physical/chemical system should be capable of treating selected wastes of this type in cases where the waste contains an immiscible organic phase which is amenable to separation by physical/chemical methods prior to incineration and, the recovered aqueous phase is amenable to further physical/chemical treatment to produce an effluent of acceptable quality.

- Physical/chemical treatment methods which are designed solely for recovering specific types of wastes, either organic or inorganic, for recycle or reuse outside the Facility have not been included for the following reasons:
  - The existing waste profile information has not identified any wastes either organic or inorganic which stand out as particularly suitable candidates for recovery and reuse.
  - The exact nature and quantities of the various waste types which will be sent to OWMC's Facility for treatment will not be known until after start up. It is therefore more practical that specific opportunities for waste recovery and reuse outside the facility be identified and evaluated after the facility has commenced operation.

- All potentially contaminated surface drainage from the landfill area, and all surface drainage from the central operating area will be collected and its quality checked before being discharged from the site. These "miscellaneous wastes" will be treated in the physical/chemical plant if they contain contaminant concentrations in excess of the effluent discharge requirements for the Facility.

- OWMC's preference is to discharge excess treated effluent from the Facility by evaporation. Treated effluents which are not suitable for final discharge by evaporation will either be retreated in the physical/chemical plant area or treated by solidification or incineration. For example, batches of treated effluent which contain concentrations of organic contaminants in excess of those which can be discharged by evaporation will be either retreated or incinerated. Similarly, batches of treated effluent which contain high concentrations of dissolved solids (eg. calcium sulphate) which could cause scaling problems in the evaporator will be solidified.

CHAPTER 3

TECHNOLOGY EVALUATION AND SELECTION

3.1 INTRODUCTION

The previous chapter outlined the framework within which the selected physical/chemical treatment processes will be expected to operate. The following sections describe in detail the methodology and criteria used to select the preferred combination of physical/chemical treatment processes which are best suited to this particular application. Chapter 3 also summarizes the results and conclusions of the technology evaluation process including the reasons for either accepting or rejecting each of the alternative generic treatment processes.

3.2 METHODOLOGY

The following points summarize the methodology used to evaluate alternative technologies for inclusion in the physical/chemical plant.

- o Establish the major treatment objectives and key treatment philosophies for the proposed physical/chemical treatment facility.
- o Establish criteria for technology selection.
- o Prepare a "long list" of possible physical/chemical technologies.

- Establish a "short list" of potentially suitable technologies and alternatives to these technologies.
- Define specific treatment requirements for each stage of physical/chemical treatment and list alternative technologies which are capable of meeting these objectives.
- Evaluate and rank the relative suitability of each technology according to the established criteria and select one or more preferred technologies for inclusion in the conceptual process design.
- Design and optimize the resulting physical/chemical treatment system to meet the treatment objectives and philosophies of OWMC.

3.3 CRITERIA FOR TECHNOLOGY SELECTION

Only proven technologies will be considered for OWMC's Treatment Facility. Technologies will be considered "proven" if they have been commercially demonstrated to perform reliably for a period of at least 12 months on a scale and in a manner comparable with that required for the OWMC Facility.

Some technologies were eliminated from further consideration based on this "screening" factor alone.

Potentially suitable physical, chemical and biological treatment technologies were evaluated against the following technology evaluation criteria:

- Performance
- Safety
- Flexibility
- Reliability
- Operational considerations

- Economic and commercial considerations
- Canadian benefits

Higher weighting factors were given to environmental factors relating to the first four evaluation criteria (performance, safety, flexibility and reliability) in determining a preferred group of treatment steps best suited to the proposed OWMC Treatment Facility. This approach ensured that OWMC's major goals to minimize risk to human health and minimize impact on the environment were being adhered to in the design of the physical/chemical plant.

A more detailed accounting of the factors which were considered in assessing each of the above mentioned technology evaluation criteria is given in the following sections.

3.3.1 PERFORMANCE

This criterion recognizes and addresses three elements crucial to the establishment and operation of OWMC's treatment facility, namely that the technologies selected:

- are those which are able to most effectively treat the wastes received,
- can be operated in a manner which is efficient in the use of energy, utilities and reagents, and
- produce minimum quantities of residues and in a form which is most amenable to further treatment, prior to ultimate disposal.

This criterion also reflects the extent to which the technologies have been used elsewhere in full scale industrial waste treatment applications.

These objectives underly the sub-criterion into which the broad category of "performance" has been divided for technology evaluation purposes. These sub-criteria will ensure that OWMC's Facility minimizes impact on the environment in the following manner.

Most Effective Treatment

Alternative physical/chemical and biological treatment processes were compared in terms of their relative ability to meet the treatment objectives for one or more stages of treatment i.e. primary treatment, secondary treatment and/or effluent polishing (see Section 3.6.1, p. 46) and, for their ability achieve the lowest possible effluent concentrations for the broadest possible range of contaminants.

A relatively high weighting has been given to this sub-criterion (50% of the criteria total) in recognition of OWMC's desire to establish a treatment facility which most effectively deals with Ontario's special waste. This ensures that the selected system will minimize the negative effects on human health and the environment.

Efficiency: Energy, Utilities, Reagents

The relative efficiency of each process with respect to energy usage, utility requirements and reagent consumption is measured by this sub-criterion.

Minimum energy use and utility requirements are desirable, not only to minimize operating costs, but to reduce impact on the existing infrastructure of the surrounding environment, and in particular the host community, to the lowest possible level.

The minimization of reagent use is desirable since the reagents are themselves potentially hazardous chemicals and their presence adds to the potential for negative environmental impact of the Facility due to the following:

- Reagent transportation to the Facility and potential releases during storage and use at the Facility.

- The contribution which reagents make to the quantity of treatment residues requiring landfill disposal, the resulting incremental increase in landfill area requirements and associated environmental impact.

Residue Characteristics

Preference is given to technologies and process systems which produce the lowest quantities of residues or conversely, those that can detoxify and concentrate residual contaminants removed from the waste for disposal, to the greatest extent. Preference is also given to technologies which produce residues:

- requiring minimum further treatment prior to disposal in the engineered landfill,
- which are most amenable to subsequent treatment,
- which are in the most convenient physical form for subsequent treatment, and
- which can be readily rendered both physically and chemically stable by solidification processes, prior to disposal in the landfill.

Selection of technologies and process systems having these characteristics will not only assure that the Facility design can operate in a cost effective manner, but also that the performance achieves OWMC's principle goals of minimizing risk to human health in the handling and treatment of residues at the Facility, and of minimizing potential for negative effects on the environment arising from treatment and disposal of these residues.

Extent Used Elsewhere

The extent to which the process system has been used elsewhere in full scale industrial physical/chemical treatment plants, is an extension of the "proven" screen used to develop the short list of potential technologies.

OWMC's definition of "proven" technology, as used in the screen, stipulates that technologies will be considered "proven" if they have commercially demonstrated to perform reliably for a period of at least 12 months on a scale and in a manner comparable with that required for the OWMC Facility. This screening evaluation has been used as arriving at a reasonable list of alternative technologies to be considered in greater detail. This sub-criterion carries the logic behind the "proven screen" one step further. In order to ascertain with any degree of certainty, the impact a technology will have on the environment, it is necessary to draw from as reliable and extensive a data base as possible in predicting the performance of that technology. The more information available, the more certain OWMC can be on the performance and the environmental impact of a technology. Preference is therefore given to those technologies which have an extensive history of satisfactory performance in similar process applications.

3.3.2 SAFETY

Results of evaluation by the "safety" criterion are the most obvious means by which OWMC measures the degree to which a technology achieves its first two corporate goals; to minimize risk to human health and to minimize impact on the environment. The criterion has been divided into two sub-criterion that correspond to these two goals, and have been given equal weighting in the evaluation process.

Occupational Risk

The occupational risk to employees at the Facility is of primary importance to OWMC, largely because the potential for negative consequences is the greatest for the personnel in closest contact with special waste at the Facility, during its handling, storage and treatment. This sub-criterion reflects OWMC's desire to minimize risk to human health.

Occupational risks may occur during normal plant conditions or during plant upsets. Risks during normal plant conditions addresses the potential for impact on the worker during everyday operation of the Facility and may cover a wide spectrum of possibilities. In the physical/chemical treatment plant, risk during normal operation might be experienced by the worker due to direct contact with wastes or fugitive emissions from wastes such as dusts or fumes.

The measure of worker risk during upset conditions acknowledges that some degree of risk may be unavoidable when using certain technologies that are required to effectively treat Ontario's special wastes. Within the physical/chemical plant, worker risks during upset conditions may, for example, result from toxic fumes or gases caused by mixing of incompatible wastes. The inclusion of this element in the selection of technologies ensures that this risk is minimized, wherever possible.

While some risks during normal and upset conditions can be avoided by selecting appropriate technologies, many more can be mitigated by design or operational procedures in the optimization of Facility design. Mitigation is dealt with in Chapter 4, System Design and Optimization.

Environmental Risk

Environmental risk during normal and process upset conditions encompasses the potential for risk, not only to the natural physical and biological environment but risk to the surrounding human population including the host community.

Technologies which provide the lowest potential for negative environmental impact will be ranked higher than other alternatives for this sub-criterion, in a manner which is consistent with OWMC's commitment to minimize risk to human health and the environment.

This sub-criterion also addresses environmental risks during both normal and process upset conditions. Environmental risk during normal operations is a measure of the threat to human health and the environment of a technology under normal operating conditions. Technologies are compared in terms of their potential for negative environmental effects in the long term, through gradual release of, and/or build-up of, contaminants in the environment.

Environmental risk during upset conditions is primarily a measure of the potential for sudden contaminant release and the risk to the environment of substances that may be released. In the physical/chemical plant, such events may arise during a power failure or malfunction of the process control and monitoring system, although events of this nature can be mitigated by design or operational procedures, as further explained in Chapter 4, System Design and Optimization.

3.3.3 FLEXIBILITY

One of the premises which guided the Facility design was a requirement that the Facility have maximum flexibility to treat a wide range of wastes. This requirement is based on the knowledge that wastes received at OWMC's Facility will cover a broad spectrum of both physical and chemical forms. The "flexibility" criterion therefore reflects the need to achieve OWMC's objectives of minimizing risk to human health and impact on the environment for a wide range of waste types and characteristics. It also assesses the ability of technologies to easily and safely handle variations in quantities of waste requiring treatment.

The following sub-criteria are used to measure the relative ability of alternative technologies and process systems in dealing with a wide range of waste types and quantities.

Waste Characteristics

This sub-criterion addresses the relative ability of alternative technologies and process systems to accommodate variations in feed composition or type of waste. The variations that will inevitably occur in the type and characteristics of waste delivered to OWMC's Facility demand that technologies included in the Facility design have capability to reduce residual contaminant discharges to the lowest practical level for a wide range of waste characteristics.

Technologies which are least sensitive to changes in waste characteristics were ranked highly for this sub-criterion.

Waste Quantities

The relative ability of alternative technologies in adapting to variations in the quantities of wastes requiring treatment, is measured by this sub-criterion.

OWMC cannot accurately predict the volumes of particular wastes it may receive, or the variations that may occur over time spans measured in years. It is desirable, therefore, that technologies be capable of effectively processing wastes over a range of feed rates.

This sub-criteria reflects in part, the relative ability of alternate technologies to operate satisfactorily at capacities significantly below their design capacity.

Rapid Startup/Shutdown

This sub-criterion recognizes that operational flexibility in achieving rapid startup and shutdown of process systems offers distinct advantages in achieving optimum utilization of treatment systems, particularly where they are operated in a batch treatment mode and/or for a limited number of hours/week such as in the physical/chemical plant. Rapid shutdown capability is also important when responding to process upsets requiring immediate response actions.

3.3.4 RELIABILITY

The "reliability" criterion measures the ability of a technology to achieve anticipated results on a consistent basis. This criterion focuses on the physical components of potential technologies and alternative process systems, the extent of their maintenance requirements, the need for spare parts, the availability of reagents and spare parts, the general robustness of the design and its vulnerability to breakdown.

All of these factors influence the reliability of a process system and the ability of the treatment Facility to achieve all three of OWMC's corporate goals. They are reflected in the following five sub-criteria, many of which are to some extent interrelated.

Maintenance Requirements

This sub-criterion reflects a preference for technologies and process systems which minimize the amount and frequency of downtime required for maintenance. It is also desirable, where possible, to avoid the use of technologies involving complex maintenance procedures.

Spare Parts

Preference is given to technologies requiring the least number and lowest cost of spare parts inventory.

Availability of Spare Parts and Reagents

This sub-criterion reflects a reluctance to utilize technologies for which spare parts and/or reagents are not readily available. Delays in obtaining either parts or reagents could result in a component of OWMC's Facility being out of operation for an extended period, and this would adversely impact on OWMC's ability to achieve its corporate goals.

Robustness of Equipment

This sub-criterion ranks technologies by the susceptibility of their components to breakdown. Efficient processing of special wastes is dependent on the ability of the equipment to withstand the rigours of extended operation, exposure to a variety of special wastes and variations in process conditions without breaking down or requiring frequent maintenance. It also minimizes costs. This sub-criterion is therefore linked to all three of OWMC's goals.

Vulnerability To Process Upset/Breakdown

The rationale for this sub-criterion is similar to the preceding one, but focuses on the process itself as opposed to the items of equipment of which it is composed. In general, the more complex the technology and the more component parts that the process system has, the more vulnerable it is likely to be to process upset and/or breakdown.

3.3.5 OPERATIONS

The inclusion of this criterion is intended to reflect OWMC's desire to have a Facility which not only has the capability of treating special wastes to the highest practical standards, but also one which is highly operable in terms of its complexity and the extent to which it can be automated. The amount and availability of specialist startup assistance and operator training required for alternative technologies, is a further consideration.

This criterion therefore has a direct bearing on OWMC's ability to achieve its corporate goals once the Facility is in operation.

Complexity

From an operational viewpoint, preference is given to those technologies and process systems which have minimum component parts, are easily understood and simple to operate and maintain.

Degree of Automation

Ranking by this sub-criterion reflects the degree of operator involvement required to monitor and control the process, and the extent to which the operator has control over the process operations, particularly the quality of discharges released to the environment.

While not always practical, an automated process is usually desirable since it removes the potential for human error in waste processing. The ability to provide a process with automatic "fail-safe" and emergency shutdown systems is considered preferable to those relying on manual initiation of safety and shutdown procedures.

Start-Up Assistance

The extent of start-up assistance and special operator training required is influenced by the complexity of Facility design and process operations.

While the nature of OWMC's Facility mandates a high level of startup assistance and special operator training by those having prior experience with the individual technologies and with similar treatment systems, preference will be given to those technologies and process systems which do not require an excessive amount of specialist input. The availability of resources to provide startup assistance and assist in operator training is a further consideration, particularly when considering the use of proprietary designs.

3.3.6 COMMERCIAL AND ECONOMIC

This criterion reflects for the most part, one of OWMC's corporate goals; the desire to minimize the cost of the Facility. Although cost is perceived as one of the negative impacts of the Facility on Ontario, this criterion is given a low weight relative to criteria that measure the minimization of impact on human health and the environment. The sub-criteria used to compare the alternative technologies and process systems are further described below.

Restrictions on Use

Preference is given to those technologies where no restrictions exist on their use by OWMC for the present or any future applications.

Cost

A high weighting (70% of the total) has been given to this sub-criterion in recognition of the third of OWMC's corporate goals. The cost factor includes consideration of capital costs, operating costs, license fees, potential for return on investment and for energy recovery.

Supplier Competition and Reliability

The extent of supplier competition in the marketplace may have an indirect bearing on the cost to OWMC of including a given technology or process system in the Facility design. The reliability of known equipment or process suppliers may have an influence on the selection of a technology if it can only be obtained from a single source, i.e. the technological advantages may be tempered by concerns regarding the supplier's ability to honour contractual commitments.

Delivery

Although unlikely at this stage of the project, it is possible that the selection of a technology or process system could be influenced by an extraordinarily long delivery period, raising concerns on whether the Facility could be completed on schedule.

3.3.7 CANADIAN BENEFITS

Alternative technologies were examined to determine whether any benefits would be accrued to Canada should one technology be selected over another. This criterion is a measure of the potential positive impacts of the Facility.

The sub-criteria used to compare the alternative technologies and process systems are further described below.

Engineering

Preference is given to technologies which can be engineered in Canada.

Supply

Preference is given to those technologies which can be supplied and/or fabricated in Canada.

Technology Transfer

This sub-criterion reflects OWMC's preference to promote the transfer of knowhow to Canadian engineers and suppliers where such knowhow can only presently be obtained outside of Canada.

Where technologies are unavailable in Canada, preference is given to technologies and/or technology vendors who are able and willing to facilitate the transfer of knowhow to Canada.

3.3.8 APPLICATION OF THE TECHNOLOGY EVALUATION CRITERIA

Each of the technology evaluation criteria outlined in the previous sections were given a numerical weighting factor which reflects the order of importance of each criteria in the technology assessment process. The weighting factors were reviewed and agreed upon with OWMC. Performance, safety, flexibility and reliability were considered to be the criteria of greatest importance in view of OWMC's stated goals to: (in order of priority) minimize risk to human health, minimize environmental impacts and minimize financial costs to OWMC and the people of Ontario. Performance, safety, flexibility and reliability were therefore given the highest overall weightings. Criteria relating to operations, commercial and economic considerations and Canadian benefits were assigned lower weighting factors consistent with these goals.

Criteria	Weighting Factor
Performance	20
Safety	20
Flexibility	20
Reliability	15
Operations	10
Commercial and economic	10
Canadian benefits	5

Each of the sub-criteria used to assess the relative performance, safety, flexibility, reliability, operations, commercial/economic and Canadian benefits associated with each technology were also assigned weighting factors to facilitate the evaluation process. These weighting factors are summarized as follows:

Criteria	Sub-Criteria		Weighting Factors
Performance			
	Most effective treatment		10
	Efficiency: energy, utilities, reagents		2
	Residue characteristics		2
	Extent used elsewhere		6
		Total	20
Safety			
	Occupational Risk		10
	Environmental Risk		10
		Total	20
Flexibility			
	Waste quantities		7
	Waste characteristics		7
	Rapid start up/shutdown		6
		Total	20
Reliability			
	Maintenance requirements		1
	Spare parts		2
	Availability of spare parts and reagents		3
	Robustness of equipment		1
	Vulnerability to process upsets or breakdowns		8
		Total	15
Operations			
	Complexity		6
	Degree of automation		3
	Start up assistance		1
		Total	10

Criteria	Sub-Criteria		Weighting Factors
Commercial and Economic			
	Restrictions on Use		1
	Cost		7
	Supplier competition and reliability		1
	Delivery		1
		Total	10
Canadian Benefits			
	Engineering		1
	Supply and fabrication of equipment		2
	Long term technology transfer		2
		Total	5

Alternative physical/chemical and biological treatment technologies were compared for their relative abilities to fulfill each of the above-mentioned criteria by assigning it a rating value from 1 to 5. Those technologies which were best suited to fulfilling a particular criterion were given the highest rating. Alternative technologies which were considered to be equivalent in their abilities to fulfill a particular criterion were given equal ratings. The ratings given each technology were multiplied by the weighting factors assigned to each criterion to arrive at a total weighted score for each technology against each of the selection criteria.

The summation of the weighted scores for each technology provides a quantitative indication of the relative suitability of each alternative physical/chemical unit operation for fulfilling a particular treatment objective within the physical/chemical plant. The higher the score the more suitable the technology. The results of these evaluations are presented in Appendix A and summarized in Section 3.7 (p. 58).

It is important to note that the total weighted scores for each technology have been used for comparison purposes to assess the overall suitability of one technology against its alternatives for fulfilling a specific treatment function. As such, the absolute values of the total weighted scores are not relevant, neither are the relative scores between technologies in different functional groups. For example, sodium hypochlorite is the preferred oxidizing reagent for this application with a total weighted score of 305 (Table A-1). Similarily pressure filtration is the preferred method of dewatering sludges for this application with a total score of 218 (Table A-5). However, the difference in total scores between these two technologies does not mean that chemical oxidation with sodium hypochlorite is a "better" technology than pressure filtration since both these technologies will perform quite different, but equally important, treatment functions within the overall physical/chemical treatment system.

It should be noted that this methodology has been adopted to assist in the technology selection process to enable all of the technology selection criteria to be accounted for in a rational manner during the evaluation process while at the same time ensuring that important selection criteria are properly accounted for. This process has not eliminated the need for qualitative evaluation and judgement in the selection of the preferred technologies but merely serves as a convenient means of quantifying such evaluations.

3.4 LONG LIST OF AVAILABLE TREATMENT TECHNOLOGIES

Arthur D. Little[12] has investigated and evaluated a total of 43 physical, chemical and biological treatment processes which were considered to be potentially applicable to the treatment of hazardous wastes. The majority of these processes plus a few additional treatment processes have been evaluated more recently by Proctor & Redfern[1] in the context of the particular requirements of the proposed OWMC treatment facility. Together these two sources have identified the possible methods of physical, chemical and biological treatment which are likely to be applicable to the treatment of hazardous wastes. The following "long list" of available generic treatment technologies derived from Arthur D. Little[12] and Proctor & Redfern[1] has therefore been used as a starting point for the evaluation and selection of the preferred combination of proven, best available treatment technologies for inclusion in the preliminary design of the physical/chemical plant.

- biological treatment[*]
- carbon adsorption
- resin adsorption
- catalysis
- calcination
- centrifugation
- chlorinolosis
- dehalogenation
- dissolution
- distillation
- electrodialysis
- electrolysis
- electrophoresis
- evaporation
- filtration
- flotation
- freeze crystallization
- wet air oxidation
- hydrolysis
- ion exchange
- liquid ion exchange
- microwave discharge
- neutralization/precipitation
- chemical oxidation
- photolysis
- coagulation/flocculation
- sedimentation
- chemical reduction
- reverse osmosis
- solvent extraction
- stripping
- ultrafiltration
- suspension freezing
- freeze drying
- zone refining
- high gradient magnetic separation

[*] See p. 108 for breakdown of various biological treatment methods. Biological treatment methods have been included in the evaluations of physical/chemical treatment technologies because biological treatment is applicable to dilute aqueous waste streams containing organic contaminants and because biological treatment processes have been used successfully alone and in conjunction with physical/chemical processes to treat industrial wastes (Arthur D. Little[12]).

3.5 SELECTION OF SHORT LIST OF POTENTIALLY SUITABLE TREATMENT TECHNOLOGIES

In order to reduce the long list of available treatment technologies to a short list of potentially suitable technologies only proven technologies were considered. Technologies which are unproven were eliminated from further consideration at the present time based on this screening factor alone. The following technologies are unproven and have therefore been eliminated from further consideration at the present time.

- dehalogenation
- electrophoresis
- freeze crystallization
- freeze drying
- suspension freezing
- zone refining

There are several other processes in the long list of available technologies on p. 35 which have been proven as effective means of improving the performance of other conventional treatment techniques but have little or no history of use as separate waste treatment processes as such. This applies to technologies such as:

- catalysis
- photolysis

These two processes have therefore not been examined as separate and discrete processes but rather as potential modifications to other conventional waste treatment processes as a means of enhancing the effectiveness of these processes. For example, catalysis is employed in Inco's air/sulphur dioxide process for oxidizing cyanides. In addition, ultraviolet light (photolysis) has been shown to enhance the performance of ozone as an oxidizing agent. Both of these processes have been evaluated as alternative chemical oxidation technologies rather than as separate catalysis or photolysis technologies.

High temperature processes such as high temperature chemical transformation and/or thermal destruction techniques designed primarily to treat organic wastes have been eliminated from further consideration for the physical/chemical treatment plant because the wastes treated in this plant are primarily inorganic. This applies to technologies such as:

- o hydrolysis
- o calcination
- o chlorinolosis
- o microwave/plasma arc discharge
- o wet air oxidation

A brief description of each of the processes mentioned is presented in the following sections along with additional reasons why each has been omitted from the short list of potentially suitable technologies. The reader is referred to Arthur D. Little[12] and/or Proctor & Redfern[1] for a more complete description of these processes.

Dehalogenation

Dehalogenation is a chemical treatment process which relies on highly reactive reagents such as sodium or sodium naphthalide to remove chlorine atoms from chlorinated hydrocarbons (PCB's, pesticides and chlorinated aromatics) to reduce their toxicity (Proctor & Redfern[1]).

This process has been eliminated from further consideration at the present time primarily because it has not been proven in full scale industrial waste treatment applications. According to Proctor & Redfern[1] this process has been evaluated in pilot plant studies on PCB wastes but not for full scale application.

Electrophoresis

Electrophoresis is the transport of electrically charged particles under the influence of a direct current electric field. According to Arthur D. Little[12] this process works on large complex molecules, colloidal or particulate matter (eg. clay), living cells (eg. bacteria) or emulsified material such as droplets of emulsified oil provided that the suspended matter has a net charge. Although this process has been used in the past in laboratory scale applications and in some industrial manufacturing processes (Arthur D. Little[12]), it is not a process which is proven in industrial waste treatment applications. The lack of water quality data demonstrating the performance of electrophoresis as a waste treatment process tends to support this conclusion. For this reason this process has been eliminated from the short list of potentially suitable processes.

Freeze Crystallization

Aqueous solutions can be purified by freezing to take advantage of the fact that the ice which forms during the freezing process will be substantially free of dissolved contaminants whereas the dissolved solids which were present in the original mixture, including any hazardous components, will be concentrated in the brine pockets which remain between the ice crystals.

Freeze crystallization is an effective concept for purifying aqueous solutions containing dissolved solids, one which has been proposed and tested for sea water desalination. However, this process has not been developed into a commercial process for use in full scale waste treatment applications. As such, freeze crystallization is not considered to be suitable this application.

Freeze Drying

Freeze drying is a concentration process which relies on the drying effects produced by the sublimation of water vapour from a frozen sample under vacuum to remove moisture from the sample. Although this process is currently being used in full scale commercial food processing plants such as in the production of freeze dried coffee, it is not a process which is currently being used in industrial waste treatment applications probably because of the long cycle times and high cost of this procedure. Because it is unproven in waste treatment applications this process is unsuitable for this application.

Suspension Freezing

Suspension freezing or freeze dewatering is a sludge conditioning process which relies on freezing to enhance the dewaterability of gelatenous, difficult to dewater sludges such as alum sludge to promote particle agglomeration and faster settling. Some installations which store sludges in ponds outdoors are able to benefit from the reductions in sludge volume which can result from the effects of natural freezing. However, sludge dewatering by artificial freezing using equipment designed specifically for this purpose, has not been developed for large scale use in waste treatment application (Arthur D. Little[12]). As such, this process is unsuitable for this application.

Zone Refining

Zone refining is a purification technique which was originally developed to refine small quantities (up to 10 kg) of pure materials such as elemental metals, semi-conducting compounds, ionic compounds and some organic compounds to produce materials of even higher purity. The process relies on the differences in composition which occur between a crystallized solid and its liquid during cooling of a liquid mixture (Arthur D. Little[12]). This process has not been used in full scale waste treatment processes nor does it appear to have much potential for use in the future. Therefore, it has been eliminated from further consideration at the present time.

Catalysis

Catalysis is not a process as such but a method of modifying chemical reactions through the use of a catalyst (or chemical additive) which causes the chemical reaction to proceed more quickly or to proceed under less severe conditions (i.e. lower temperature and pressure). An example of the use of a catalyst in hazardous waste treatment can be found in Inco's recently developed process for oxidizing cyanides in wastewater. This process uses air and sulphur dioxide in the presence of copper as a catalyst to oxidize cyanides. Bernardin[14] has also reported the benefits of copper as a catalyst to promote the oxidation and adsorption of cyanide on activated carbon.

It is not practical to evaluate catalysis as a generic process technology as such since catalysts serve only to enhance some types of chemical reactions. In addition, the selection of an appropriate catalyst is very specific to the type of chemical reaction being carried out. In waste treatment applications catalysts are most often used to enhance the efficiency of chemical oxidation reactions. Therefore it is in this context that technologies which are known to require catalysts (such as Inco's Air/SO_2 process) have been evaluated. In other cases, potential benefits which may be obtained through the use of catalysts can only be evaluated through laboratory treatability testing of actual wastes on a case by case basis. OWMC's Facility will be equipped to carry out such tests.

Photolysis

Photolysis is a process which uses light energy, usually ultraviolet (UV) light, to break chemical bonds. A vast majority, if not all, of the full scale applications of this technology have involved its use in conjunction with other reagents (usually oxidants) such as chlorine and ozone as a means of enhancing the oxidation reaction. It is in this context, as an alternative chemical oxidation process, that this technology has been evaluated. (Refer to Section 3.7.2, p. 65).

Hydrolysis

Hydrolysis is a chemical transformation process which is in widespread use as a manufacturing process in industry. One example is in the production of soap by the alkaline hydrolysis of fats. Hydrolysis reactions also take place in waste treatment applications. For example according to Stumm and O'Melia[15], hydrolysis products are thought to be responsible for the coagulating effects observed during particle aggregation with iron and aluminum salts (i.e. alum and ferric chloride).

Hydrolysis reactions are carried out in a wide variety of equipment depending on the required process conditions from simple open top tanks to specialized reactors. These include countercurrent towers, tubular reactors, tray contactors, autoclaves, open tanks and pressure vessels (Arthur D. Little[12]). Specialized hydrolysis reactions, particularly those involving organics usually require elevated temperatures and sometimes elevated pressures. As indicated above, hydrolysis can be applied to inorganic components. However they are most often applied to organics. According to Arthur D. Little[12] hydrolysis can be applied to a wide range of aliphatic and aromatic organics such as esters, ethers, carbohydrates, sulphonic acids, halogen compounds, phosphates and nitrites. Strong acids such as sulphuric acid and strong alkalis such as sodium hydroxide are often used for acid or alkaline hydrolysis of organics.

Specialized processing equipment such as high temperature, high pressure reactors for carrying out hydrolysis reactions can not be justified at the present time. Therefore, in this context, hydrolysis as a separate and distinct processing technology has been eliminated from further consideration for the following reasons:

- The existing waste profile information does not indicate a requirement for specialized equipment for this purpose.

- Reagent requirements (type and quantity), processing conditions (temperature and pressure) and optimum equipment configurations must be evaluated and selected on a case by case basis to be of any use in reducing the toxicity of a particular waste component using specialized hydrolysis reactors.

- The benefits of hydrolyzing a particular waste component must be evaluated on a case by case basis since the byproducts of some hydrolysis reactions, particularly those involving organic compounds, may not necessarily be less toxic than the original components (Proctor & Redfern[1]).

- The physical/chemical treatment facility will have a built in capability for carrying out hydrolysis reactions which can be carried out in standard, non pressurized, stirred reaction tanks because this equipment as well as strong acid and alkaline reagents will be required for other treatment processes such as oxidation, reduction, neutralization/precipitation and emulsion breaking.

Bench scale treatability tests will be used to determine in advance whether a hydrolysis reaction should be included in the treatment formulation for a particular batch of waste.

Calcination

Calcination is a thermal decomposition process which oxidizes organic components of aqueous liquids and sludges into solid materials and gases at elevated temperatures (usually 650 to 1200°C). This process can be carried out in any of three basic types of equipment either multiple hearth, rotary kiln or fluidized bed configurations. A rotary kiln incinerator has been chosen as the primary treatment method for the destruction of organic wastes which will require treatment at OWMC's Facility. Therefore, there is no reason for this processing capability to be duplicated in the physical/chemical process area. The justification and rationale for selecting a rotary kiln for inclusion in the incineration plant is discussed in a separate report. (Arthur D. Little[4])

Chlorinolosis

Chlorinolosis is a process which converts waste chlorinated hydrocarbons into shorter chain chlorinated hydrocarbons (usually carbon tetrachloride) in the presence of heat (500°C) pressure (above 50 atm) and excess chlorine. This process has been rejected from further consideration at the present time for the following reasons:

- According to Arthur D. Little[12], this process was developed primarily as a manufacturing process for the production of carbon tetrachloride rather than as a waste disposal process. As a result, information is lacking on the efficiency of conversion and the concentrations of unreacted hydrocarbons present in the process effluent. It is therefore not possible to adequately evaluate the performance of chlorinolosis as a waste treatment process or to compare its performance with that of alternative methods of disposing of chlorinated organics other than in very general terms.

- Although chlorinolosis may have some future application as a method of producing a salable byproduct from organic wastes, insufficient data are currently available on the specific characteristics of the chlorinated organic wastes likely to require treatment at OWMC's Facility to enable a chlorinolosis plant to be justified. Such information is not expected to be available until after the facility has been in operation for a period of time and the types, quantities and characteristics of potentially suitable chlorinated organic wastes are more precisely known along with the market conditions for reselling the byproduct carbon tetrachloride which would result from this process.

- The rotary kiln incinerator provides a proven and reliable means of destroying all organic wastes (solid or liquid, chlorinated or non chlorinated) which are likely to require treatment at OWMC's Facility. A chlorinolosis plant, even if it could be justified at the present time, would not eliminate the need for the rotary kiln but would provide only the potential for recovering a salable byproduct from a select fraction of the chlorinated organic wastes which are expected to require treatment at the facility.

Microwave/Plasma Arc Discharge

Microwave discharge and related plasma arc technologies are thermal processing techniques primarily intended for high temperature destruction of organics. These techniques have been demonstrated in the laboratory and are currently in the development stages as an alternative means of achieving thermal destruction of hazardous wastes (Proctor & Redfern[1]). As such, it is appropriate that this technology be evaluated in relation to alternative thermal processing techniques rather than for physical/chemical treatment of inorganics. Microwave/plasma arc discharge has therefore been excluded from further consideration for use in the physical/chemical plant.

Wet Air Oxidation

Wet air oxidation is a thermal treatment process which involves the aqueous phase oxidation of organic and inorganic materials at elevated temperature (175 to 320°C) and high pressure (typically 10 000 kPa or more) (Turner[37]).

This process is generally applicable to aqueous organic waste streams which contain between 1% and 20% organics or other oxidizable materials (Proctor & Redfern[1]). Historically, wet air oxidation has been used primarily for oxidizing sewage sludges and pulp mill effluents. Although chlorinated aliphatics and some halogenated aromatics are capable of being oxidized by this process, chlorinated benzenes, chlorinated pesticides and PCB's are reported to be resistant to wet air oxidation (Turner[37]).

Wet air oxidation has been rejected from further consideration at the present time for the following reasons:

- The rotary kiln incinerator has been selected as the preferred means of destroying all organic wastes (chlorinated or non chlorinated, dilute or concentrated) which are likely to require treatment at OWMC's Facility.

- In view of the superior capabilities of the rotary kiln for treating all types of organic wastes in a wide range of physical forms, the only advantage which would be gained by including a wet air oxidation system in the OWMC Facility would be to reduce the operating costs of treating some selected aqueous organic wastes which are too dilute to be incinerated (without blending them with higher heating value wastes or auxiliary fuel) and too concentrated for cost/effective treatment by activated carbon. The overall cost/benefit of including wet air oxidation for these waste types will ultimately depend on the total quantity of dilute aqueous waste received at the Facility which can be treated satisfactorily by wet air oxidation. Since these waste quantities will only be known after the OWMC Facility is in operation, further detailed consideration of this process is best left until after startup.

Summary

The long list of thirty-five available technologies has been reduced to the following shorter list of twenty-two potentially suitable technologies by eliminating those technologies discussed in the previous sections.

- biological treatment
- carbon adsorption
- resin adsorption
- centrifugation
- dissolution
- distillation
- electrolysis
- electrodialysis
- evaporation
- filtration
- flotation
- high gradient magnetic separation
- ion exchange
- liquid ion exchange
- neutralization/precipitation
- chemical oxidation
- coagulation, sedimentation
- chemical reduction
- reverse osmosis
- solvent extraction
- stripping
- ultrafiltration

3.6 EVALUATION OF POTENTIALLY SUITABLE TREATMENT TECHNOLOGIES

As indicated previously, none of the potentially suitable physical/chemical or biological processes are capable of fulfilling all of the treatment functions required to produce the desired effluent quality for all tvpes of waste. Technologies which are capable of achieving very low residual contaminant concentrations generally require one or more pretreatment steps in order to achieve their potential for producing an effluent which contains the lowest possible concentrations of contaminants. Conversely, pretreatment steps (primary and secondary treatment) will generally benefit from additional effluent polishing to remove residual concentrations of dissolved and suspended contaminants. The optimum physical/chemical treatment process will therefore consist of a number of stages of treatment each able to contribute to the overall treatment objective.

The purpose of the technology evaluation procedure has been to:

- define the types of treatment functions required at each stage of the treatment process,
- identify, from the list of potentially suitable technologies, alternative processes which are capable of fulfilling each treatment function, and to
- select, for each stage of treatment, one (or more) processes which best satisfy the technology evaluation criteria.

The requirements for each stage of the physical/chemical treatment process are discussed in the following sections. The rationale for the selection of the preferred combination of physical/chemical treatment technologies is discussed in Section 3.7 (p. 58).

3.6.1 TREATMENT OBJECTIVES

The waste profile information has a major influence on the manner in which the treatment objectives are defined for all stages of the physical/chemical treatment process. The precise characteristics of the wastes which are likely to require treatment at the Facility are not known and aren't likely to be known with any degree of certainty until the Facility is in operation. The treatment objectives for each stage of the treatment process have therefore been developed with this in mind.

The following conclusions have been drawn regarding the basic physical/chemical treatment objectives based on the existing waste profile information.

Primary Treatment

For the purposes of OWMC's physical/chemical treatment plant, primary treatment is defined as a first stage of treatment designed to prepare certain wastes for additional levels of treatment.

Untreated wastes which require physical/chemical treatment could be in solid form (non-pumpable), liquid form, in mixtures of solids and liquids ranging from slurries to pastes or, in mixtures of two immiscible liquids (such as oil and water).

The first stages of the physical/chemical treatment process must therefore have the capability for the following types of treatment:

- Dissolution and/or slurrying of solid or semi solid wastes which require further secondary treatment to chemically stabilize the waste. This would apply to solid or semi solid wastes which can not be solidified directly (such as solid sodium cyanide or cyanide containing sludges).

- Separation of bulk suspended solids from aqueous solutions prior to either thickening and solidification, direct solidification or incineration of the recovered solids and further treatment of the recovered liquid.

- Bulk physical separation of two immiscible liquid phases (eg. oil and water) to enable the organic phase to be recovered (for incineration) and to prepare the aqueous phase for further treatment.

- In addition to the above-mentioned treatment functions, it will be necessary to provide a capability for blending and/or equalization of compatible wastes prior to further treatment as a means of maximizing the efficiency of subsequent processing steps.

It is emphasized that although "primary" treatment has been defined as the first stage of physical/chemical treatment, not all untreated wastes are likely to require one of the above-mentioned forms of primary treatment prior to "secondary" level treatment. Those wastes which would not benefit from dissolution (or slurrying), phase separation or blending would be routed directly to one or more of several "secondary" treatment steps. Thus the distinction between primary and secondary treatment processes is a somewhat arbitrary one which has been adopted to illustrate the requirement for the physical/chemical treatment processes to be utilized in a staged manner to achieve maximum reduction of dissolved and suspended contaminants from untreated waste to final treated effluent.

Secondary Treatment

For the purposes of OWMC's physical/chemical treatment plant, the term secondary treatment is defined as a second stage of treatment designed to prepare inorganic and aqueous organic wastes for subsequent final effluent polishing and solidification. The secondary level physical/ chemical treatment processes are therefore aimed at chemically stabilizing the waste and reducing the concentrations of both dissolved and suspended contaminants to the maximum extent possible in preparation for polishing the partially treated effluent and solidifying the resulting inorganic residues.

The waste profile information indicates that a combination of the following treatment steps will be required for a majority of inorganic and aqueous/organic wastes in order to chemically stabilize, detoxify and/or concentrate these wastes prior to effluent polishing and/or solidification.

- Oxidation to destroy oxidizable contaminants such as cyanides, sulphides, ammonia, organometallic complexes and dissolved organics.
- Reduction to convert hexavalent chromium into trivalent chromium prior to subsequent secondary treatment to remove the trivalent chromium.
- Neutralization and precipitation to neutralize acidic and alkaline wastes and precipitate dissolved heavy metals.

- Coagulation and solids separation to remove precipitated suspended solids.

- Sludge dewatering to concentrate the recovered solids prior to solidification.

- Emulsion breaking to destabilize mixtures of emulsified organics in water.

- Oil-Water separation to separate immiscible organic and inorganic phases after demulsification.

It should be noted that there are no alternatives as such to each of these forms of treatment only alternative "methods" of carrying out each of these treatment steps. It is these alternative treatment "methods" which are discussed and compared in the following sections (see Section 3.7, p. 58).

Each of these treatment steps is considered to be an essential process for inclusion in the physical/chemical treatment plant for the following reasons:

- The available waste profile information indicates that a majority of the contaminant types mentioned above are likely to be present in various concentrations in a significant proportion of the wastes which are expected to require treatment in the physical/chemical plant.

- These particular treatment steps are proven and widely used (in varying combinations) in industrial waste treatment applications which treat wastes that are similar in nature to those expected to require treatment at OWMC's Facility.

- o All of these treatment steps are currently being used successfully in other state-of-the-art regional physical/chemical treatment facilities such as HIM in Frankfurt, West Germany and GSB in Ebenhausen, West Germany.

Biological treatment has not been included at this stage of the treatment process because of the potential toxic effects that high concentrations of heavy metals and perhaps some toxic organics could have on these processes. Instead, biological treatment has been evaluated as an alternative polishing step for the removal of residual dissolved organics.

In addition to the above-mentioned secondary treatment processes, several other treatment processes are worth examining as possible additional secondary treatment processes for the removal of specific contaminants. These are:

- o Stripping to reduce concentrations of ammonia and hydrogen sulphide.

- o Distillation to recover selected organic wastes for resale or reuse.

- o Solvent extraction to reduce high concentrations of dissolved organics such as phenol.

Effluent Polishing

Effluent polishing is defined as the final stage(s) of physical/ chemical treatment designed to remove residual concentrations of suspended solids, dissolved inorganics (including total dissolved solids in general) and dissolved organic contaminants prior to recycle and/or final discharge to atmosphere by evaporation.

Effluent polishing treatment steps have been included in the preliminary design of the physical/chemical process area for the following reasons:

- To ensure that wastes receive the best possible treatment.

- To ensure that treated effluents are of a suitable quality with respect to process requirements and protection of human health to enable them to be reused on site.

- To ensure that treated effluents are of a suitable quality to enable them to be discharged from the facility by evaporation to atmosphere at minimum risk to human health and with minimum risk to the environment.

Due to the inherent uncertainties and extreme variability of the wastes which are likely to require treatment in the physical/chemical plant it is not possible to accurately predict the specific types and concentrations of inorganic and organic contaminants which are likely to remain in the partially treated waste after secondary treatment, (Refer to Section 4.5.2 p. 178). The following general conclusions can however be drawn regarding the treatment requirements of the effluent polishing steps.

- The secondary solid/liquid and liquid/liquid separation processes could leave residual concentrations of finely divided suspended solids containing metal hydroxides and metal sulphides or residual immiscible organics such as very fine dispersed oil droplets which would benefit from polishing by physical treatment methods such as filtration.

- Some wastes could contain residual concentrations of dissolved inorganic contaminants such as heavy metal cations, nutrients (nitrate and phosphate), fluoride, cyanide (as ferricyanide or ferrocyanide) which would benefit from effluent polishing to further reduce the concentrations of these constituents in the final effluent.

- A majority of the partially treated wastes are likely to contain high concentrations of non-toxic dissolved solids such as sodium, calcium, sulphate, chloride and carbonate. Batches of concentrated waste which require large reagent dosages during secondary treatment could have total dissolved solids concentrations as high as 8 % by weight. Effluent results from the HIM regional physical/chemical treatment facility in Frankfurt indicate that the total dissolved solids concentration of their treated effluent ranges from 1 to 8 % by weight with an average of between 4.5 and 5 % by weight. A majority of the partially treated wastes would therefore benefit from effluent polishing steps to reduce their concentrations of total dissolved solids prior to reuse.

- The physical/chemical treatment system will require some capability for removing dissolved organic contaminants which may be present in the inorganic wastes which are designated for physical/chemical treatment. For example, aqueous wastes containing immiscible oil and grease may contain low concentrations of phenol which must be removed from the aqueous phase after physical separation of the organic phase. The waste profile information also indicates that organic contaminants (such as organic acids, dyes, paint and ink pigments, solvents, detergents and soaps, toluene and other organic solvents, styrene, acrylonitrile, glycerine, starch, resins, mineral spirits and others) could be present in some batches of inorganic waste requiring physical/chemical treatment. Although the exact nature and concentration of the dissolved organics which are likely to be present in these wastes is unknown and expected to vary significantly from batch to batch, it is considered to be advantageous to include polishing steps which are capable of removing additional dissolved organics from the partially treated wastes.

Alternative Technologies

The alternative treatment methods for achieving each of the specific treatment objectives outlined in the previous sections for the primary treatment, secondary treatment and effluent polishing steps are summarized in Table 3. Each of the potentially suitable treatment technologies listed on p. 45 are represented in Table 3 in bold face print according to the particular treatment function which they are best suited to fulfilling. Some technologies are capable of fulfilling more than one treatment function and are listed accordingly.

In some cases such as neutralization, chemical oxidation and chemical reduction, the selection of one (or more) suitable reagents from a list of alternatives could have an influence on the performance, safety, flexibility and reliability of a particular treatment technology. In these cases alternative reagents have also been listed in Table 3 for comparative evaluation.

The comparison of alternative technologies and the rationale for the selection of the preferred combination of treatment technologies to be included in the physical/chemical process area are outlined in the following sections.

TABLE 3
SUMMARY OF ALTERNATIVE PHYSICAL/CHEMICAL TREATMENT METHODS

TREATMENT REQUIREMENTS	ALTERNATIVE TREATMENT METHODS	COMMENTS
1.0 PRIMARY TREATMENT STEPS		
1.1 Phase Separation (liquid/liquid or solid liquid)	o **Sedimentation** o **Centrifugation** o **Air Flotation** o **Filtration**	o To separate two immiscible liquids (aqueous and organic) to recover the organic phase for disposal by incineration o To separate bulk suspended solids from liquid prior to solidification or incineration of recovered solids o As a pretreatment step for the aqueous phase prior to secondary treatment
1.2 **Dissolution** and/or Slurrying	o Using water, acid, alkali or organic solvents	o Pretreatment step for solid wastes prior to secondary treatment
1.3 Blending and/or Equalization	o Inline o Mixing Tank	o To mix compatible wastes prior to subsequent treatment steps to maximize the use of available equipment

NOTES: **Technologies indicated in bold face type correspond to those potentially suitable treatment technologies listed on p. 45.**

TABLE 3 (Cont'd)
SUMMARY OF ALTERNATIVE PHYSICAL/CHEMICAL TREATMENT METHODS

TREATMENT REQUIREMENTS	ALTERNATIVE TREATMENT METHODS	COMMENTS
2.0 SECONDARY TREATMENT METHODS		
2.1 Oxidation	o **Electrolysis** o **Chemical Oxidation** using chlorine, sodium hypochlorite, calcium hypochlorite, hydrogen peroxide, potassium permanganate, ozone, air/sulphur dioxide	o Destruction of cyanides and sulphides o Oxidize ammonia and ammonia/metal complexes o Oxidize dissolved organics eg. phenols, organic sulphur compounds o Oxidize trivalent arsenic (As^{3+}) to pentavalent arsenic (As^{5+})
2.2 Reduction	o **Electrolysis** o **Chemical Reduction** using sulphur dioxide, sodium metabisulphite, sodium bisulphite, sodium sulphite, sodium hydrosulphite, ferrous sulphate sodium borohydride	o Reduction of hexavalent chromium (Cr^{6+}) to trivalent chromium (Cr^{3+}) o Reduction of ionic mercury (Hg^{2+}) to metallic mercury (Hg)
2.3 **Neutralization** and **Precipitation**	o Using hydrated lime, quicklime, limestone, sodium hydroxide, soda ash	o To neutralize acidic wastes and precipitate heavy metals, fluoride and phosphate
	o Using sulphuric acid, hydrochloric acid	o To neutralize alkaline wastes
	o Using ferric chloride, ferric sulphate, ferrous sulphate	o To precipitate arsenic
	o Using sodium sulphide, sodium hydrosulphide, iron sulphide	o To precipitate residual heavy metals (eg. mercury and cadmium) to low levels
2.4 **Coagulation/** Emulsion Breaking	o Using ferric chloride, ferric sulphate, ferrous sulphate, alum, polyelectrolytes	o To co-precipitate arsenic and other heavy metals and coagulate suspended solids
	o Using heat, acid, polyelectrolytes	o To break oil water emulsions

N. Technologies indicated in bold face type correspond to those potentially suitable treatment technologies listed on p. 45.

TABLE 3 (Cont'd)
SUMMARY OF ALTERNATIVE PHYSICAL/CHEMICAL TREATMENT METHODS

TREATMENT REQUIREMENTS	ALTERNATIVE TREATMENT METHODS	COMMENTS
2.5 Secondary Phase Separation	o **Sedimentation** o **Filtration** o **Centrifugation** o **High Gradient Magnetic Separation** o **Flotation**	o Remove coagulated suspended solids from partially treated waste streams o Remove immiscible oil and grease after emulsion breaking
2.6 Sludge Dewatering	o **Centrifugation** o **Filtration** using pressure filters, vacuum filters, belt filter presses	o Thicken treated sludges prior to solidification or incineration
2.7 Other Secondary Treatment Processes		
o Removal of Volatile Organics	o **Stripping**	o For removal of ammonia, hydrogen sulphide and volatile organics from aqueous wastes
o Recovery of Organic Solvents and/or Selected Organic Contaminants	o **Solvent Extraction** o **Distillation**	o To remove specific organic compounds (eg. phenol) from aqueous wastes o To recover organic solvents from aqueous wastes

NOTES: Technologies indicated in bold face type correspond to those potentially suitable treatment technologies listed on p. 45.

TABLE 3 (Cont'd)
SUMMARY OF ALTERNATIVE PHYSICAL/CHEMICAL TREATMENT METHODS

TREATMENT REQUIREMENTS	ALTERNATIVE TREATMENT METHODS	COMMENTS
3.0 EFFLUENT POLISHING TREATMENT STEPS		
3.1 Removal of Residual Suspended Matter	o **Ultrafiltration** o Granular Media **Filtration** Microscreening	o Removal of residual suspended solids and oil and grease
3.2 Removal of Dissolved Organics	o **Ultrafiltration** o **Carbon Adsorption** o **Resin Adsorption** o **Biological Treatment**	o Removal of residual dissolved organics
3.3 Removal of Dissolved Inorganics	o **Reverse Osmosis** o **Evaporation** o **Electrodialysis** o **Ion Exchange** o **Liquid Ion Exchange**	o Removal of residual dissolved heavy metals o Removal of residual nuisance anions eg. fluoride, nitrate and phosphate o Reduction of other dissolved solids in treated effluent

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[b] **Technologies indicated in bold face type correspond to those potentially suitable treatment technologies listed on p. 45.**

3.7 SELECTION OF PREFERRED TREATMENT TECHNOLOGIES

The relative suitability of the alternative technologies given in Table 3 for each step of the physical/chemical treatment process has been evaluated to provide a basis for selecting a preferred combination of treatment steps for inclusion in the conceptual physical/chemical process design.

For completeness, a brief description has been given for each of the alternative technologies as they are discussed in the following sections. A majority of this information has been summarized from Proctor & Redfern[1] and Arthur D. Little[12] as well as other miscellaneous references listed at the end of this report. For more complete descriptions of each of the generic processes, the reader should refer to these sources.

In cases where one technology can be shown to be clearly superior to its alternatives for fulfilling a particular treatment function its selection has been justified based on overall qualitative consideration of its relative performance, safety, flexibility and reliability, compared to its alternatives. In these cases it has not been necessary to undertake a more in-depth comparative analysis which takes into account all of the technology selection sub criteria outlined in Section 3.3 (p. 32) and their respective weightings. This applies primarily to the assessment of treatment steps where there are fewer alternatives to choose from or where choice of a preferred approach is obvious based on the reasons cited.

In some cases, the choice of one or more preferred technologies from a group of alternatives is not as obvious and requires a more detailed consideration of each of the sub criteria outlined in Section 3.3 (p. 32). The methodology which has been adopted to assist in this evaluation process and enable all of the technology evaluation criteria to be accounted for in a rational manner has been outlined in Section 3.3.8 (p. 31).

The following sections summarize the major reasons for selecting certain processes and excluding others from the preliminary process design. Appendix A contains additional details where applicable on the relative rankings for each group of alternative technologies.

3.7.1 PRIMARY TREATMENT

Liquid - Liquid Phase Separation and Solid Liquid Separation

As indicated in Section 3.6.1 (p. 46) some batches of waste may benefit from a pretreatment step to separate bulk flotable oil and settleable suspended solids prior to subsequent secondary treatment steps designed to treat the recovered phases separately. There are five treatment technologies which are potentially suitable for this purpose.

- sedimentation
- centrifugation
- air flotation
- filtration
- high gradient magnetic separation

Gravity sedimentation is a physical separation process which takes advantage of the fact that solid or liquid particles which are suspended in a liquid having a different specific gravity will tend to either settle to the bottom or float to the surface under quiescent conditions.

Gravity sedimentation is the preferred method of achieving primary liquid/liquid and solid/liquid separation for wastes which require this type of pretreatment for the following reasons:

- Gravity sedimentation can take place in the inorganic waste storage tanks themselves if this step is required thereby eliminating the need to provide additional items of equipment in the plant to achieve this treatment objective.

- Gravity sedimentation is the most commonly used and least expensive method of pretreating aqueous wastes for the separation of bulk flotable oils and settleable solids.

- Although centrifugation, air flotation and filtration are all capable of achieving better performance for some treatment applications, gravity separation is capable of handling a wider range of influent concentrations compared to the other alternatives and therefore provides a more effective and reliable means of achieving phase separation for untreated wastes of widely varying characteristics.

- Centrifugation, air flotation and filtration have each been selected for various secondary treatment requirements. Therefore the capabilities of each of these technologies will be available in the physical/chemical process area if required.

The alternative methods for carrying out primary liquid/liquid and solid/liquid separation have been rejected for use at this particular stage of the treatment process for the following reasons.

Centrifugation is a physical separation process which separates solid or liquid particles which are suspended in a liquid having a different specific gravity by means of a mechanically induced centrifugal force. Since centrifugal forces can be created which are several thousand times the force of gravity in sedimentation the efficiency of the separation process can be improved particularly for smaller suspended particles.

Gravity separation is the preferred method of achieving primary phase separation for a majority of the wastes which are expected to require this form of primary treatment. Centrifugation is considered to be less disireable for this purpose for the following reasons:

- The use of a centrifuge for removing bulk settleable solids and flotable oil would not necessarily eliminate the need for subsequent secondary treatment steps. Depending upon the efficiency of separation the centrate may still require further treatment to remove finely divided suspended solids or oil particles which can not be removed by centrifugation.

- Gravity sedimentation offers advantages in terms of flexibility and reliability over centrifugation for use as a primary treatment step because gravity sedimentation enables waste storage and phase separation functions to be combined and because it does not rely on mechanical means to achieve the treatment objective.

- However, centrifugation has been selected as the preferred means of separating aqueous and organic phases following emulsion breaking (p. 92). It is therefore practical from a system design point of view to make maximum use of the capabilities of centrifugation for either primary or secondary phase separation where appropriate. This feature is highlighted further on p. 157.

Air flotation is a physical treatment process which uses extremely small air bubbles which attach themselves to suspended particles in the waste causing these particles to be floated to the surface for removal. Conventional dissolved air flotation involves dissolving air in the waste under pressure such that, when the pressure is released, minute air bubbles are formed. A variation on this called induced air flotation involves creating small air bubbles by means of specially designed mechanical agitators. Air flotation is commonly used for the supplemental treatment of oil-water separator effluents for reducing oil and suspended solids to low levels. Although air flotation could be used for primary solids/liquid and liquid/liquid separation for some wastes it does not have the flexibility for dealing with a broad range of suspended solids and immiscible liquid concentrations when compared to gravity separation. As such air flotation is fundamentally a secondary treatment process which should be preceeded by gravity separation or centrifugation to reduce the required volume of air and flocculating chemicals and obtain optimum waste clarification. For these reasons air flotation has been rejected as a primary solid/liquid and liquid/liquid separation process.

Filtration is a well proven physical separation process which separates suspended particles from liquids by forcing the liquid through a porous medium. The choice of an appropriate filter medium is determined primarily by the particular filtration application.

Granular media filters use various combinations of sand, gravel, and coal as a filter medium. These types of filters are used primarily for removing residual suspended particles either solid or liquid from waste streams. For high solids containing streams it is necessary to reduce the suspended solids concentration to the extent possible by flocculation and/or sedimentation in order to reduce the suspended solids load to the filters (Arthur D. Little[12]). Since granular media filters are not well suited to handling the broad range of suspended solids concentrations expected in the untreated wastes, this process has been rejected as a primary phase separation step in favour of further evaluating this process as an effluent polishing step.

Plate and frame pressure filters and fixed media, continuously renewed surface filters such as rotary vacuum units, belt filter presses and microstrainers are better suited to applications involving concentrating and dewatering slurries or sludges. In addition, precoat pressure and vacuum filters are capable of producing a very high quality filtrate containing very low concentrations of residual suspended solids. The major disadvantage of fixed media filtration devices for primary phase separation is that they are not able to handle large quantities of immiscible liquid in water.

However there is clearly a requirement for sludge dewatering capability within the physical/chemical plant. In a majority of cases, sludge dewatering will be required as a secondary treatment step after precipitation of dissolved solids to minimize the volume of solid residues requiring solidification. For some waste it may be advantageous to dewater certain pumpable sludges directly as a primary treatment step prior to subsequent separate treatment of the filtrate and recovered solids.

Alternative technologies for sludge dewatering have therefore been evaluated in detail in a later section of this report and a preferred method of treatment, in this case gravity thickening followed by pressure (plate and frame) filtration, has been selected for inclusion in the preliminary process design. The capabilities of sludge dewatering equipment can therefore be utilized as a primary treatment step for selected wastes either alone or in combination with gravity sedimentation without including additional filtration equipment specifically for this purpose.

High gradient magnetic separation is a relatively new solids separation process which is designed primarily for removing magnetic and paramagnetic particles from liquids and slurries. The solids containing feed stream is passed through a magnetized filter matrix consisting of woven steel fabric, compressed steel wool or expanded metal. A high intensity magnetic field is generated in the void spaces of the filter mesh with magnets. This causes the magnetic particles to be retained in the filter mesh. The magnetic field is turned off periodically to enable the filter matrix to be washed clean. Non magnetic particles can only be removed by seeding the feed stream with magnetic material plus a flocculant. The major advantage of high gradient magnetic separation is that it can operate at much higher flow rates compared to other solids separation processes. Its major disadvantage is that it is designed primarily for removing magnetic particles particularly where there is some potential for contaminant recovery and resale. According to Arthur D.Little[12] for non magnetic particles, equivalent performance can be obtained with inexpensive and more widely used solids separation and filtration processes. For this reason HGMS has been eliminated from further consideration for this application.

Dissolution and/or Slurrying

Dissolution is a primary treatment step which involves the chemical transfer of one or more components of a solid phase (solute) into a liquid phase (solvent). The most common solvent used in waste treatment applications is water although many aqueous chemicals such as acids (sulphuric, hydrochloric, nitric) alkalis (sodium hydroxide), complexing agents (ammonia, cyanide) and oxidizing agents (air, chlorine) can also be used to selectively dissolve various components of the solid phase.

Dissolution is a pretreatment step which is employed for the purpose of preparing a waste for further treatment involving separation, recovery, stabilization or destruction of the species dissolved from the solids.

Dissolution and/or slurrying will be required for non-pumpable wastes which require physical/chemical treatment prior to solidification. For example, solid sodium cyanide or cyanide-containing sludges will have to be dissolved in water at alkaline pH to dissolve the cyanide prior to treatment by chemical oxidation to destroy the cyanide.

Apart from the selection of an appropriate solvent (which must be done on a case by case basis) there are no alternative dissolution technologies as such to chose from. Dissolution operations make use of standard mixing tanks and agitation equipment which will be required for oxidation, reduction and neutralization reactions. In addition, the most commonly used solvents i.e. water, sulphuric acid and sodium hydroxide, will also be available in bulk in the physical/chemical building. Any other reagents which may be required for specialized cases can be obtained on an as required basis. The physical/chemical plant will therefore have the capability for dissolving selected solid wastes which may require further physical/chemical treatment.

Blending and/or Equalization

Blending and/or equalization are primary treatment steps designed to enable batches of compatible wastes to be combined into a single, larger batch prior to treatment thus enabling more efficient use to be made of subsequent treatment process equipment. Blending can take place either in-line or in a mixing tank. Equalization is generally carried out in a mixing tank to achieve a longer residence time. Since all of the waste storage tanks will be equipped with agitators for the purpose of keeping solids in suspension, the system will have an inherent capability for blending and/or equalizing compatible wastes where practical.

3.7.2 SECONDARY TREATMENT

Oxidation

Oxidation is a chemical transformation process whose primary function in the treatment of hazardous wastes is to detoxify oxidizable compounds in a waste stream by chemically changing such compounds into other compounds which are less toxic. For example, cyanide can be detoxified by oxidizing it to form nitrogen and carbon dioxide.

Oxidation can be carried out thermally using high temperatures and oxygen (air) to carry out the reaction, biologically using microorganisms, chemically using oxidizing chemicals such as chlorine, ozone, hydrogen peroxide and others or, electrolytically using an electrical potential (voltage) applied to conductive electrodes which are immersed in the waste stream.

Alternative technologies for carrying out thermal oxidation (incineration) of hazardous wastes are evaluated in previous reports (Proctor & Redfern[1], Arthur D. Little[4]) and are therefore not discussed here.

Biological treatment is generally classified as a secondary treatment process in municipal waste treatment applications. However, for purposes of evaluating the usefulness of biological treatment for treating the types of waste which are likely to be treated in the physical/chemical process area of OWMC's treatment Facility, biological treatment has been evaluated as a polishing step for the removal of residual dissolved organics. This approach was taken to ensure that biological treatment methods were not eliminated from further consideration prematurely based on their inability to deal with the high concentrations of toxic inorganics (such as heavy metals) which are likely to be present in the wastes during the secondary treatment processes.

Chemical and electrolytic oxidation processes are alternative generic physical/chemical treatment technologies which are both capable of destroying toxic contaminants such as cyanides. Chemical oxidizing agents differ in terms of their cost/effectiveness and ease of use. Therefore, several chemical oxidants which are more commonly used in waste treatment applications have been evaluated and compared to electrolysis as a means of oxidizing toxic components (organic and inorganic) in wastes which are likely to require treatment in the physical/chemical plant. The results of these comparisons are presented in Table A-1, Appendix A and summarized below.

Electrolysis is a process which has been used in waste treatment applications primarily for recovering heavy metals from concentrated solutions and for treatment of metal cyanide wastes. The process involves passing a direct electric current through a metal bearing solution by means of a cathode and anode submerged in the solution. The positively charged metal ions migrate to the cathode and are deposited (chemically reduced) to their metallic form. These metal values can be recovered by periodically removing the accumulated deposits from the surface of the cathode. Cyanides are destroyed by a combination of electro-oxidation and electro-chlorination in which chloride ions in the waste solution are oxidized to form chlorine which in turn reacts with cyanides much in the same way as the conventional alkaline chlorination process.

Table 4 illustrates the achievable treatment levels for electrolytic oxidation compared to various chemical oxidizing agents. These data indicate that from a performance point of view, none of these alternatives would appear to offer any real advantage. In most cases, the final cyanide concentration after oxidation ranged from 0 to 0.5 mg/L. One possible advantage to electrolytic methods would appear to be their ability to handle very high influent cyanide concentrations. Normally, cyanide wastes which contain more than 5000 mg/l of cyanide are diluted to approximately this value prior to chemical oxidation. This is currently the practice in at least one European waste treatment facility (HIM in Frankfurt, Germany). However, this apparent advantage is more than offset by the extremely long reaction times required to destroy very high concentrations of cyanide by electrolytic methods. This is illustrated in Table 5 (p. 68).

TABLE 4
OXIDATION OF CYANIDE WASTEWATERS
ACHIEVABLE TREATMENT LEVELS

Treatment Process	Cyanide Concentration (mg/L) Initial	Final	Percent Removal
ELECTROLYTIC OXIDATION			
Electrolysis	45 000 - 100 000[5]	0.1 - 0.5	99.99+
Electrolysis	20	0.5	97.5
CHEMICAL OXIDATION			
Alkaline Chlorination(1)(7)	NI[6]	1.7	-
Alkaline Chlorination(1)	NI	0.1	-
Alkaline Chlorination(2)	NI	0.4	-
Alkaline Chlorination(2)	700	0.0	100
Alkaline Chlorination	32.5	0.0	100
Alkaline Chlorination(3)	5.1	0.1	98
Ozone	25	0.0	100
Kastone Process(4)	350 - 400	0.3	99.9+

Notes:
(1) Single Stage Chlorination
(2) Two Stage Chlorination
(3) High pH, High Temperature Process
(4) Hydrogen Peroxide plus Formaldehyde at 120 to 130°F
(5) Refer to Table 5
(6) NI - Not Indicated
(7) The use of either chlorine (Cl_2), sodium hypochlorite (NaOCl) or calcium hypochlorite $Ca(OCl)_2$ will produce equivalent effluent results since these are essentially the same reagent in different forms

Source: Patterson[16]

TABLE 5
ELECTROLYTIC DECOMPOSITION OF CYANIDE WASTE

Run No.	Initial Cyanide Concentration mg/L	Final Cyanide Concentration (mg/L)	Time To Decompose (Days)
1	95 000	0.1	16
2	75 000	0.2	17
3	50 000	0.4	10
4	75 000	0.2	18
5	65 000	0.2	12
6	100 000	0.3	17
7	55 000	0.4	14
8	45 000	0.1	7
9	50 000	0.1	14
10	55 000	0.2	8
11	48 000	0.4	12

Source: Patterson[16]

Electrolysis was ranked below conventional chemical oxidation techniques in terms of its overall suitability for this particular application for the following reasons:

- Electrolytic processes are primarily suited to treating and/or reclaiming heavy metals in solution but are not particularly useful for oxidizing dissolved organics. Chemical oxidation methods on the other hand are capable of fulfilling both of these treatment requirements (Arthur D. Little[12]).

- Depending upon the reaction time allowed, additional chemical treatment may be required in addition to electrolysis to reduce the concentrations of residual heavy metals and cyanide to the maximum extent possible prior to final effluent polishing. (Proctor & Redfern[1])

- The equipment required to carry out electrolysis is more complicated than that required for chemical oxidation and therefore more prone to process upset conditions due to mechanical breakdown.

- The advantages of electrolytic methods for recovering valuable heavy metals are likely to be offset to a large extent by the fact that a majority of the wastes which are expected to require treatment in the physical/chemical plant will probably contain a mixture of heavy metals which when recovered will reduce the resalability of the recovered product. Furthermore, as indicated in Section 2.5 (p. 17), the existing waste profile information does not indicate whether any wastes are likely to contain specific metal values in recoverable concentrations. Particular opportunities for metal recovery by electrolysis can therefore only be evaluated once the Facility is in operation. At this point it may be practical to re-examine the merits of electrolysis as a metal recovery technique for specific wastes which have an identified resale market.

Chemical Oxidation has been selected in favour of electrolytic oxidation methods because of its greater flexibility and reliability for treating the types of wastes which are likely to require physical/chemical treatment at OWMC's Facility. As indicated in Section 3.6.1 (p. 48) an oxidation step will be required as part of the secondary treatment process in the physical/chemical plant primarily to destroy cyanides but also to detoxify other oxidizable contaminants such as sulphides, ammonia, organometallic complexes and, to a lesser extent, dissolved organics. Alternative oxidizing reagents have been evaluated with these requirements in mind.

Two such reagents, sodium hypochlorite as the main oxidant and hydrogen peroxide as a backup oxidant have been selected for inclusion in the preliminary process design based on the factors summarized in the following sections and outlined in Appendix A.

It is important to recognize that, with the exception of ozone which must be generated on site using specialized equipment, the equipment requirements for carrying out all chemical oxidation reactions are the same regardless of the type of oxidant selected. Therefore, if laboratory treatability were to indicate that a particular oxidant, other than the ones stored on site, were better suited to destroying a specific contaminant present in one or more batches of waste, equipment limitations would not prevent the alternative oxidant from being used on an as required basis.

Sodium hypochlorite (NaOCl) has been selected as the primary oxidant to be used for a majority of the wastes which require chemical oxidation prior to additional secondary treatment. Sodium hypochlorite, also known as industrial bleach, is generally sold in bulk tank truck or tank car lots as an alkaline solution containing 12 % by weight available chlorine. It has been selected as the preferred oxidant for this application for the following reasons:

- Liquid sodium hypochlorite is safer to handle and store compared to pressurized liquid chlorine.

- Liquid sodium hypochlorite is safer and more convenient to feed particularly at larger dosages compared to solid reagents such as calcium hypochlorite and potassium permanganate which must either be handled and fed directly as a solid or dissolved to form a pumpable solution. Both procedures carry an increased risk of operator exposure to dusts and fumes.

- During the destruction of cyanides with sodium hypochlorite, caustic soda is produced as a byproduct of the reaction thus alleviating the need to add supplementary caustic (such as required with liquid chlorine) to maintain an alkaline pH and prevent the formation of toxic hydrogen cyanide gas.

- The sodium salts added to the wastewater by the use of sodium hypochlorite are much less likely to cause downstream equipment scaling problems compared to the calcium salts added through the use of calcium hypochlorite.

- Sodium hyochlorite is currently being used as the oxidant of choice in European physical/chemical treatment facilities which are functionally comparable to the type of physical/chemical plant planned for OWMC's treatment Facility.

Hydrogen peroxide (H_2O_2) is sold as an aqueous solution containing 35, 50 or 70 percent concentrations of hydrogen peroxide. It is shipped in 200 L drums, 15 m^3 tank wagons and 15 to 37 m^3 railroad tank cars.

Hydrogen peroxide is proven to be effective in oxidizing a wide range of reduced sulphur compounds including hydrogen sulphide (H_2S), polysulphides (S_x^{2-}), polythionates ($S_xO_6^{2-}$), and others as well as other oxidizable contaminants such as cyanide, phenols, and photographic chemicals such as hydroquinone ($C_6H_6O_2$) and silver salts.

The major advantages of hydrogen peroxide are that it is easy and convenient to store and feed as a liquid and, more importantly, its decomposition products are water and oxygen. Therefore, no additional dissolved solids are added to the waste being treated. Its major disadvantages are its higher cost (1.5 to 2 times that of sodium hypochlorite based on oxidizing cyanide to cyanate) and the fact that hydrogen peroxide has been reported to be somewhat less effective on metal complexed cyanides such as copper and nickel complexes compared to other oxidants including sodium hypochlorite (Ingles and Scott[17]).

Despite this, hydrogen peroxide offers a major advantage over other chemical oxidants, with the exception of ozone, in terms of its ability to minimize the total dissolved solids concentrations in the treated effluent from the secondary treatment processes and thereby reduce the total dissolved solids which require removal at the effluent polishing stages. In addition, because it is available in liquid form in 200 L drums it can be stored in small quantities in the physical/chemical treatment building for use on an as required basis without tying up expensive storage and feeding equipment. For these reasons, hydrogen peroxide has been selected as an alternative oxidizing reagent.

Chlorine (Cl_2) is one of the most commonly used oxidants and alkaline chlorination (chlorine plus caustic for pH control) is perhaps the most widely used and best proven method of destroying cyanides in full scale treatment operations. Chlorine is shipped in liquified form under pressure in 4.5 kg and 68 kg cylinders, in 907 kg containers and in single-unit tank cars of approximately 50 t and 82 t capacity.

The major advantage of liquid chlorine is its low cost compared to the alternative reagents being considered.

The major disadvantage of chlorine relates to the safety aspects associated with storing and handling pressurized liquid chlorine which, if exposed to air, vapourizes rapidly to toxic chlorine gas. It is primarily for this reason that liquid chlorine has been rejected in favour of sodium hypochlorite as the preferred oxidant primarily because hypochlorite can provide equivalent performance without the occupational and environmental risks associated with using chlorine.

Calcium hypochlorite ($Ca(OCl)_2$) is a solid material containing approximately 65% available chlorine which is normally shipped in 45 kg fibre drums. It can be used directly in its solid granular form with adequate mixing or, it can be mixed with water to form a stock solution. Its major advantage over liquid chlorine is the fact that it is a stable solid which is relatively easy to store and use. Its major disadvantages relate to the handling problems and labour requirements involved in feeding calcium hypochlorite in solid form from 45 kg containers or in mixing the stock solutions particularly for batches which require large doses of this chemical. For example, to oxidize one batch per day of cyanide waste containing 3% (30 000 mg/L) of cyanide would require handling and feeding approximately twenty 45 kg drums of reagent. This quantity would of course be higher if the concentration of cyanide or other oxidizable constituent in the waste were higher. It is worth noting that regional physical/chemical treatment facilities in Europe such as HIM and GSB in Germany receive cyanide wastes containing concentrations ranging from 1 to 70 000 or 80 000 mg/L of total cyanide.

Detailed information is not available on the normal and maximum concentrations of cyanide and the frequency with which they are likely to arrive at OWMC's Facility for treatment. Therefore, reagents such as sodium hypochlorite which are delivered by bulk tanker truck, unloaded via a closed piping system and delivered to the point of use in a closed piping system offer greater flexibility, convenience and operator safety advantages over alternative solid reagents such as calcium hypochlorite which must either be dissolved prior to being fed as a liquid or added directly via an opening in the top of the reaction tank. In addition the use of any calcium based reagent such as calcium hypochlorite would be expected to increase the likelihood of downstream equipment scaling problems resulting from the formation of gypsum ($CaSO_4$) and calcium carbonate ($CaCO_3$).

Potassium permanganate ($KMnO_4$) is also shipped and stored in solid crystalline form. Although it has been used for the destruction of organic residues in waste water and potable water and reacts with a range of organic contaminants including aldehydes, mercaptans, phenols and unsaturated acids, it has not been widely used for waste treatment applications primarily because other, equally effective, reagents are available at lower cost. Potassium permanganate reduces to manganese dioxide (MnO_2) which itself is a nuisance contaminant which must subsequently be removed by filtration. Because it is supplied in crystalline form, potassium permanganate has many of the same disadvantages that other solid reagents have in terms of their ease of handling, flexibility and potential hazard to workers particularly at higher chemical dosages. For these reasons, it is not a preferred choice for this particular application.

Ozone (O_3) is a powerful oxidizing agent which must be generated on site for immediate use using specialized equipment. Ozone is generated from air or pure oxygen either by the action of ultraviolet (UV) light or by means of an electric (corona) discharge. A majority of the commercially available full scale ozone generators are still of the corona discharge type although UV units are available for small commercial applications.

The major advantages of ozone are as follows:

- No dissolved solids are added to the waste stream being treated.
- Ozone is capable of oxidizing a wide range or organic and inorganic contaminants and has been proven in full scale installations designed to destroy wastes such as cyanides, waste dyes and phenols.
- Ozone when used in combination with UV light is one of the few oxidants which are capable of oxidizing very stable iron cyanide complexes (Ingles and Scott[17]).

Despite these advantages ozone has a number of disadvantages which make it unsuitable for inclusion in the preliminary design of the physical/chemical plant. These are:

- Oxidation with ozone lacks the flexibility of liquid oxidants for adapting to wide variations in feed composition. The rate of generation of ozone is fixed by the size of the ozone generating equipment therefore, batches of waste with higher oxidizable contaminant concentrations will require longer batch cycle times (perhaps days) to complete the oxidation reaction. According to Arthur D. Little[12] oxidation using ozone is generally practical for streams containing less than 1000 mg/L of oxidizable material. As indicated previously, it is entirely possible that a number of the wastes which will require physical/chemical treatment at OWMC's Facility could contain oxidizables in concentrations well in excess of 1000 mg/L, perhaps as high as 70 000 or 80 000 mg/L based on the European experience.

- Although modern ozone generation equipment is very reliable by most standards, this specialized equipment by its very nature is inherently less reliable and more costly to repair compared to the liquid chemical based systems which do not depend on specialized items of equipment for their operation.

- It is significant to note that despite the fact that ozonation has found wide spread full scale use as disinfectant in European water treatment applications, it has not been the method of choice for use in European physical/chemical waste treatment facilities which are comparable to the proposed OWMC Facility. This is likely due to advantages such as lower capital cost and increased flexibility offered by chemical oxidation methods which employ hypochlorite and the highly toxic nature of ozone gas itself.

Although the disadvantages of ozonation have been considered sufficiently important to warrant excluding this process from further consideration at the present time, it is recommended that ozonation be given further serious consideration after OWMC's Facility has been in operation for a period of time, when the waste profile characteristics can be better defined and when actual samples of wastes which require oxidation are available to carry out treatability tests using ozone alone and in combination with ultraviolet light.

Air/Sulphur dioxide process is a relatively new process for the removal of free and complexed cyanide in wastewaters which has been developed by Inco Laboratories. The process uses sulphur dioxide, (either as a gas or as a solution of sodium bisulphite) plus air and lime. This process has been demonstrated in laboratory and pilot scale treatment operations but only to a very limited extent in full scale applications. This process has been developed and evaluated primarily for oxidizing cyanides in wastewaters. Cyanide removal is achieved by a combination of cyanide oxidation to cyanate and by precipitation of insoluble ferrocyanide salts.

The air/SO_2 process has the following disadvantages which make it unsuitable for inclusion in the preliminary process design of the physical/chemical treatment plant.

- The process requires copper ions in concentrations up to 50 mg/L to be present in the solution being treated to act as a catalyst. If copper is not already present in the waste water it must be added from an external source. Since copper is one of the more toxic heavy metals which must be removed to very low residual concentrations in the treated effluent, therefore, the possibility of having to add one toxic contaminant in the process of removing another (i.e. cyanide) is an undesirable feature of this process.

- The process will not completely oxidize cyanide to nitrogen and carbon dioxide. Some of the cyanate will however hydrolyze to ammonia and carbon dioxide. The ammonia must subsequently be treated by further oxidation.

- Although the process has been used in full scale operations it has not been widely used outside the mining industry.

- The process has not been proven effective on other oxidizable contaminants which are likely to require treatment in the physical/chemical process area such as sulphides, ammonia, phenols and other organics.

Reduction

Reduction-oxidation or "redox" reactions are chemical transformation reactions in which the chemical oxidation state of one or more chemical components in a mixture is raised while that of another is lowered. In waste treatment, reduction reactions are used to lower the oxidation state of a particular component of the waste in order to reduce its toxicity, reduce its solubility or transform it into a chemical form that can be easily removed by physical separation techniques (Proctor & Redfern[1]).

It is necessary that a reduction step be included in the design of the OWMC's physical/chemical treatment plant for the following reasons:

- The existing OWMC waste profile information and waste treatment experience in comparable installations indicates that wastes containing widely varying concentrations from a few parts per million to several thousand parts per million of hexavalent chromium (Cr^{6+}) are expected to be treated in OWMC's physical/chemical treatment plant. Reduction of hexavalent chromium to the trivalent state (Cr^{3+}) followed by precipitation of the trivalent chromium is the best proven and most widely used method of treating chromium containing wastes. Other technologies such as activated carbon, reverse osmosis, ion exchange and evaporation which could potentially be used to remove or recover hexavalent chromium (along with other heavy metal cations) have been evaluated elsewhere in this report.

- Chemical reduction has been used in full scale industrial waste treatment applications for over 25 years.

- Chemical reduction is currently being used successfully in several European regional physical/chemical treatment facilities in Europe (notably HIM and GSB in Germany) which are functionally comparable to the type of facility required for OWMC.

- Chemical reduction is an effective method of treating other toxic heavy metals such as mercury and lead by reducing these metals to their metallic form to facilitate their removal by physical separation techniques.

Reduction reactions can be carried out either chemically (using chemical reducing agents) or electrolytically (by means of an externally applied direct current). The equipment requirements are identical to those described for electrolytic and chemical oxidation processes outlined in the previous section (p. 65). The only difference between these processes is the different choice of reagents required to bring about a reduction reaction in the waste vs an oxidation reaction.

Electrolytic Reduction has been excluded from further consideration at the present time for similar reasons to those outlined previously in Section 3.7.2 (p. 66). Particular opportunities for chromium recovery by electrolysis can of course be re-examined once the facility has been in operation for a period of time and the waste profile is better defined.

Chemical Reduction has been selected as the preferred reduction method.

As indicated in Table A-2 Appendix A, several of the more commonly used chemical reducing agents have been evaluated and compared for use at OWMC's Facility. The preferred choice has been made primarily on occupational safety, environmental safety and ease of use considerations since the achievable effluent levels are comparable regardless of the reagent chosen.

Table 6 summarizes the treatment levels reported for several of the most commonly used chemical reducing agents plus results for other technologies capable of reducing hexavalent chromium. These results indicate that all of these technologies are capable of achieving equivalent effluent results for hexavalent chromium with no single technology capable of achieving outstandingly low effluent values compared to its alternatives.

Sodium metabisulphite ($Na_2S_2O_5$) is a white free flowing crystalline solid which is readily soluble in water and reacts as a weak acid and as a mild reducing agent. On addition to water sodium metabisulphite forms sodium bisulphite.

Sodium bisulphite ($NaHSO_3$) is the preferred reducing reagent for this application for the following reasons.

- It has been proven to be an effective alternative source of sulphur dioxide and is the reagent of choice in European physical/chemical treatment facilities which are comparable to OWMC's Facility.

- It is cost competitive with sulphur dioxide in cases where sulphur dioxide is not obtained in railcar lots.

- The occupational safety and environmental hazards associated with using bisulphite are lower compared with those associated with the shipping, handling and storage of sulphur dioxide.

Since bisulphite is the most widely used and best proven alternative to sulphur dioxide without the safety hazards of sulphur dioxide, it has been selected as the preferred reducing agent for this application.

TABLE 6
SUMMARY OF TREATMENT LEVELS REPORTED FOR HEXAVALENT CHROMIUM WASTES

Treatment Process	Chromium (Cr^{6+}) Concentration (mg/L) Initial	Final
Chemical Reduction		
Sulfur Dioxide	--	0.3-1.3
Sulfur Dioxide	--	1.0
Sulfur Dioxide	1300	"zero"
Sulfur Dioxide	--	0.01
Sulfur Dioxide	--	0.05
Sulfur Dioxide	0.23-1.5	0.1
Bisulfite	140	0.7-1.0
Bisulfite	--	0.05-0.1
Bisulfite plus Hydrazine	8-20.5	0.1
Metabisulfite	70	0.5
Metabisulfite	--	0.025-0.05
Metabisulfite	--	0.1
Metabisulfite	--	0.001-0.4
Ferrous Sulfate	--	1.0
Electrochemical Reduction		
Cementation	16.3	0.09
Other Treatment Processes		
Ion Exchange	--	0.023
Ion Exchange	--	0.025
Ion Exchange	8-10.7	0.0-0.9
Activated Carbon(1)	0.09-0.19	0.17 (ave.)
Activated Carbon(1)	5.0	0.006-0.087
Activated Carbon(1)	100-820	5.05-195
Freeze Concentration(1)	100	0.225

(1) Pilot plant results.

Source: Patterson[12]

Sulphur dioxide (SO_2) is a colourless gas at room temperature and atmospheric pressure. It is shipped as a liquid and gas mixture in pressurized cylinders (68 kg), ton containers (907 kg), and single unit tank cars (50 t or 82 t capacity). The major advantages of sulphur dioxide are:

- It is the most commonly used reagent for reducing hexavalent chromium to trivalent chromium.

- Sulphur dioxide is usually the least expensive of the alternative reducing agents particularly where chemical consumption is large and sulphur dioxide is purchased in tank car lots.

The major disadvantages of using sulphur dioxide relate primarily to the safety and/or hazards which could occur under upset conditions such as ruptured lines or leaking joints. Although sulphur dioxide is in wide spread use in industry and can be handled and fed safely if the proper precautions are taken, it is an irritant chemical which will effect the nose and throat even at low concentrations 25 to 38 mg/m^3 and can be fatal in some cases at concentrations as low as 1300 mg/m^3 (ref. CIL[18]). For this reason, sulphur dioxide has been rejected in favour of bisulphite as the preferred choice of reducing reagent for this application.

Sodium Sulphite (Na_2SO_3) is an odourless white granular solid which is shipped in bags (22.5 kg and 45 kg) and 180 kg fibre drums. Sodium sulphite has many of the same advantages and disadvantages as other reducing agents which are supplied in solid form. However it is less widely used compared to bisulphite for chromium reduction applications and offers no particular advantage over bisulphite. For these reasons it is not the preferred choice for this application.

Sodium Hydrosulphite ($Na_2S_2O_4$) is a white free flowing uniformly crystalline product which is a very reactive chemical and a strong reducing agent which is classified as a flammable solid. It is shipped in 115 kg steel drums. Sodium hydrosulphite is not a preferred reducing reagent for this application primarily because of the additional care which must be taken when handling this chemical which can decompose when exposed to air and moisture with sufficient heat to cause ignition.

Ferrous sulphate ($FeSO_4 . 7H_2O$) is a crystalline solid which is shipped in 25 kg bags. Ferrous sulphate in bag form is not a preferred reducing agent for this application because of its relatively high cost (1.5 times that of the equivalent quantity of sodium metabisulphite) and the fact that more than four times the amount of sludge is produced by using ferrous sulphate compared with sodium based reducing agents. Despite these disadvantages, ferrous sulphate, when it is available as spent pickling liquor, is a viable alternative to the use of purchased reducing agents because it enables one waste stream to be used to treat another. Opportunities such as this would be exploited wherever possible in the treatment of wastes at OWMC's treatment Facility.

Sodium borohydride ($NaBH_4$) is sold either as a white crystalline solid containing 97% sodium borohydride or as a stabilized water solution of 12% sodium borohydride in caustic soda. Because of its ease of handling and high reducing power per unit weight of chemical, it is sometimes used for specialized smaller scale reduction reactions, for example to reduce mercuric ions to mercury metal to enable the mercury to be removed by filtration. It is not a preferred reducing agent for this application primarily because alternative more commonly used reagents are available which give equivalent performance at lower cost. However, this does not prevent sodium borohydride from being purchased on an as required basis for the treatment of small specialized batches of waste particularly those which may contain recoverable concentrations of heavy metals such as mercury.

Neutralization and Precipitation

Neutralization is a chemical treatment process in which an acid is mixed with a base to neutralize the acidity or alkalinity of a waste stream. Solutions with a pH of less than 7 are acidic whereas those with a pH of greater than 7 are basic (or alkaline). Neutralization is essentially a pH adjustment process designed to change the pH of a strongly acidic (low pH) or strongly alkaline (high pH) waste stream to an acceptable value. The adjustment of the pH of a waste stream to exactly neutral (pH 7) is not always necessary or desirable therefore the term neutralization is sometimes used to describe adjustment of pH to values other than 7 but usually within the range of pH 6 to 9. Neutralization is effective on both inorganic waste acids and alkalis as well as organic compounds such as carboxylic acids, sulphonic acids, phenol and others.

The existing waste profile information indicates that a significant proportion of the wastes which are likely to require treatment in the OWMC physical/chemical treatment plant may be strongly acidic (low pH) or strongly alkaline (high pH). Neutralization is the only technology which is capable of adjusting the pH of these wastes to an acceptable value. Therefore, a neutralization step will be required as part of the physical/chemical process design.

Precipitation is a physical and chemical transformation process which involves altering the chemical equilibrium of a solution to cause soluble components in the solution to become insoluble and form a solid (precipitate) which can subsequently be separated from the solution by physical separation techniques. Precipitation can be achieved in basically three ways:

- Chemical reagents can be added to shift the chemical equilibrium of a solution and cause one or more components to precipitate out of solution as a solid as a new chemical equilibrium is reached. The neutralization of acidic solutions which contain dissolved heavy metals is an example of this type of precipitation reaction. As the pH of the solution is increased the dissolved heavy metals become less soluble and precipitate out as insoluble metal hydroxides. The extent to which this will occur is dependent upon the particular metal and the final pH of the solution.

- o Chemical reagents other than neutralizing reagents can be added which react chemically with specific soluble components in a solution to form an insoluble compound. Metal sulphides (such as mercury sulphide and lead sulphide) are examples of insoluble compounds which are formed when a soluble compound (sodium sulphide) is added to a solution containing dissolved heavy metals (eg. mercury and lead). Sulphide precipitation is a process which is applicable to a wide variety of other toxic heavy metals as well.

- o The temperature of the solution can be changed. Since solubility is temperature dependent, by changing the temperature of a saturated or nearly saturated solution in the direction of decreasing solubility (in most cases by cooling the solution) the chemical equilibrium is changed which will cause one or more components to precipitate out of solution as a solid as the new chemical equilibrium is reached. This particular method of achieving precipitation is of limited usefulness and not widely used in waste treatment applications because a majority of toxic inorganic contaminants (such as heavy metals) are usually not present in concentrations which are at or near saturation. This approach to precipitation is not applicable to this situation and has therefore been dropped from further consideration.

Precipitation reactions will often occur during the neutralization of wastes as a result of the equilibrium shift brought about by the changing pH of the mixture. Therefore, by equipping OWMC's physical/chemical treatment plant to carry out neutralization of strong acidic and alkaline wastes will also enable the plant to carry out precipitation reactions. The equipment requirements are exactly the same for both processes.

The following sections summarize the rationale for selecting the preferred combination of neutralization and precipitation reagents.

It should be emphasized that the selection of a preferred combination of reagents for inclusion in the preliminary process design does not necessarily mean that other reagents can not be used for specific batches of waste where bench scale treatability tests indicate that it is advantageous to do so. The preferred reagents are those which are expected to be used most often. It is, therefore, appropriate to design facilities to store and handle these in larger quantities. A majority of the alternative reagents are available in small quantities (bags or drums) and can therefore be purchased for occasional use on an as required basis.

Alkaline Reagents

The most common alkaline reagents currently used for neutralization of acids in waste treatment applications are:

- calcium based reagents such as hydrated lime ($Ca(OH)_2$), quicklime (CaO) and limestone ($CaCO_3$),
- sodium based reagents such as sodium hydroxide ($NaOH$) and sodium carbonate or soda ash (Na_2CO_3), and
- magnesium based reagents usually in the form of dolomitic lime and limestones which contain a combination of calcium and magnesium oxides or carbonates.

Hydrated lime ($Ca(OH)_2$) is one of the most common alkaline reagents used in waste treatment applications. It is shipped in dry powdered form in 22.5 kg bags or in bulk tank truck lots. Because of its low solubility in water hydrated lime is usually fed as a dilute (15 % by weight) slurry. As such it is convenient and safe to store and used particularly when purchased in bulk form. Due to its widespread use there is an abundance of performance data on the effectiveness of lime either alone or in combination with other precipitation reagents for removing a wide variety of contaminants from waste streams (USEPA[10]).

For these reasons lime has been chosen as the preferred alkaline reagent for carrying out neutralization and precipitation reactions in the physical/chemical plant.

Quicklime (CaO) is the product resulting from the calcination of limestone and forms the raw material for the production (slaking) of hydrated lime. It is supplied in bags and in bulk blower truck and tank car lots. For maximum efficiency in using quicklime in chemical processes involving aqueous solutions it is desirable to slake the quicklime to form hydrated lime. This is normally done on site using slaking equipment specifically designed for this purpose. Due to the additional processing steps involved this operation is usually not economical or practical unless there is a sufficiently high lime demand. Hydrated lime is generally preferred for applications which involve up to 115 t/a and sometimes as much as 180 t/a (National Lime Association[18]). It is not possible to predict with any accuracy the expected lime demand for treating wastes in the physical/chemical process area. However, it is unlikely that the demand will be large enough to justify the additional capital expense and potential operating problems associated with operating a slaker particularly since every effort will be made, during the execution of the required treatment processes, to use one type of waste to treat another to reduce the overall reagent requirements of the process. The use of quicklime in place of hydrated lime is not considered to be advantageous for this application.

Limestone ($CaCO_3$) is the least reactive and least soluble of the calcium based reagents. It is sometimes used in large volume waste treatment applications such as mine waste water treatment where reagent cost is a major consideration and downstream equipment scaling and sludge disposal is not a particular concern because of the availability of large tailing ponds for sludge storage. Since these conditions do not apply to OWMC's treatment Facility, limestone is not a preferred reagent choice for this application.

Despite their low cost, all of the calcium based reagents have one major disadvantage that is, their use increases the possibility of scale formation in equipment and piping particularly where the wastes being treated are high in sulphate and carbonate. Since this situation could arise with wastes being treated at OWMC's Facility it is necessary to have an alternative sodium or magnesium based alkaline reagent available on site to be used in place of lime in cases where it is advantageous to do so.

Sodium hydroxide (NaOH) and **sodium carbonate** or soda ash (Na_2CO_3) are the two reagents which are best suited as alternatives to lime where scaling is likely to be a problem. High magnesium (dolomitic) lime is not considered to be a particularly suitable alternative because this material still contains almost 50% calcium oxide. Sodium hydroxide is the alternative reagent of choice for this application for the following reasons:

- Sodium hydroxide is available in bulk form as a concentrated (50%) solution thus making it more convenient to store and feed than soda ash which is only available in solid form.

- The neutralization products which result from the use of sodium hydroxide are very soluble therefore potential downstream scaling problems are minimized.

- Carbon dioxide is produced in volume during the neutralization of strong acids with sodium carbonate. In some cases this can cause severe foaming problems.

- Sodium hydroxide has a higher basicity factor than sodium carbonate i.e. less sodium hydroxide is required to carry out a given neutralization reaction compared to sodium carbonate.

It is important to emphasize that despite their advantages, sodium based neutralizing reagents can not entirely replace the use of calcium based reagents. In some cases, for example wastes which contain high fluoride or phosphate concentrations, lime will provide a distinct advantage over sodium hydroxide in terms of its ability to achieve maximum removals of fluoride and phosphate as insoluble calcium salts.

Acidic Reagents

The two most common acidic reagents currently used for neutralization of alkalis in waste treatment applications are sulphuric acid (H_2SO_4) and hydrochloric acid (HCl). Sulphuric acid is the preferred choice for this application for the following reasons:

- At normal temperatures and at a concentration of 98% or lower sulphuric acid has comparatively little odour.
- Hydrochloric acid on the other hand is an extremely active mineral acid which fumes strongly in moist air.
- Carbon steel is satisfactory for storage tank lines and other equipment for commercial grade sulphuric acid strengths (93%).
- Commercial grade hydrochloric acid 31 to 37% requires rubber lined steel for storage tanks and transfer lines.
- Sulphuric acid is less expensive than hydrochloric acid. (approximately 3 times on an equivalent weight basis.)

Other Precipitation Reagents

The performance and flexibility of the physical/chemical treatment system for achieving maximum removals of high concentrations of dissolved contaminants by precipitation can be further enhanced by providing the capability for storing and handling other precipitation reagents as discussed in the following sections.

Two additional reagents, ferric chloride and sodium hydrosulphide, have been chosen to enhance the performance and flexibility of the precipitation steps and achieve maximum removals of toxic contaminants (primarily heavy metals).

Ferric Chloride ($FeCl_3$) is available either as a dark brown solution of 38 to 45% $FeCl_3$ shipped in tank truck or tank car lots, in drums (60 and 160 kg sizes), or as solid crystals containing 98% $FeCl_3$. As a result of its high floc forming power it has been given widespread use as a coagulant aid and precipitating agent for a wide range of contaminants including nutrients (eg. phosphates) and a majority of heavy metals. Ferric chloride has been selected in favour of other sources of dissolved iron such as ferric sulphate ($Fe_2(SO_4)_3$) and ferrous sulphate ($FeSO_4$) and other coagulants such as alum ($Al_2(SO_4)_3 \cdot 14H_2O$) for the following reasons:

- Ferric chloride is available in bulk solution form which eliminates the requirement for operator involvement in handling and dissolving dry chemicals such as ferrous sulphate and ferric sulphate. This minimizes the chances of operator exposure during unloading and feeding.

- The potential for scaling is minimized by using ferric chloride rather than ferrous or ferric sulphate because of the high solubility of its reaction products.

- Iron hydroxide sludges are more easily dewatered by filtration compared to aluminum hydroxide sludges.

Sodium hydrosulphide (NaHS) is supplied as a 45% aqueous solution. It is an alkaline liquid which is shipped in 200L drums, in tank trailers and insulated tank cars. Many heavy metals have been successfully removed to very low levels by means of precipitation using sulphide salts in conjunction with lime and other coagulant aids. Sulphide precipitation will be required in many cases to achieve the lowest possible residual levels of dissolved metals by precipitation. Sodium hydrosulphide has been selected as the preferred reagent in favour of solid sodium sulphide primarily because it is available in solution form thus facilitating the safe handling and feeding of this chemical.

Coagulation

Coagulation and flocculation are synonymous terms which are used interchangeably to describe a combined physical and chemical process whereby chemical coagulating agents (or flocculants) are added to a waste water containing finely divided suspended particles in order to cause these particles to agglomerate (coagulate) to form larger, more rapidly settling particles. Although coagulation is a term which is used most often to describe aqueous wastes containing finely divided suspended solids, the same principles apply to the demulsification of oil/water mixtures. Coagulation is considered to be a "required" secondary treatment step in the physical/chemical plant for the following reasons:

- The neutralization and precipitation steps discussed in the previous section will produce a mixture of finely divided (colloidal) solids consisting of metal hydroxides, metal sulphides, metal carbonates and calcium salts (calcium sulphate, calcium carbonate) which can not be physically separated from the aqueous phase without coagulation.

- A majority of the aqueous organic mixtures which are amenable to physical/chemical treatment will contain emulsified oil and grease which must be coagulated (demulsified) to enable the aqueous and organic phases to be physically separated.

The most common coagulating chemicals are hydrated lime ($Ca(OH)_2$), iron salts (such as ferric chloride), alum ($Al_2(SO_4)_3 \cdot 14H_2O$) and various organic flocculating agents known as polyelectrolytes (or polymers). The rationale for the selection of lime and ferric chloride as preferred reagents for carrying out neutralization and precipitation reactions has been summarized previously (pp 85 and 89). The same rationale applies to the use of these chemicals as coagulating agents. The equipment is the same. In a majority of cases, the mechanisms involved in chemical neutralization, precipitation, co-precipitation and coagulation take place simultaneously.

Polyelectrolytes are high molecular weight compounds which act as bridges to reduce the natural repulsive forces which exist between charged colloidal particles (solids or liquids) in suspension. They can be used alone as coagulant aids or in combination with other coagulants such as lime and ferric chloride to improve the performance of these chemicals. They are also used in a majority of mixed media filtration and sludge dewatering applications to improve the filterability of liquids and dewatering characteristics of sludges. They are also widely used in the destabilization of oil/water and other aqueous/organic emulsions (such as latex wastes). As such, polyelectrolytes will be an important and necessary addition to OWMC's physical/chemical treatment system.

There are a vast number of different types of polyelectrolytes available on the market each designed to perform a specific range of treatment functions. It is not necessary or practical to choose one or more specific polyelectrolytes for use in the physical/chemical treatment system. This must be done by means of bench scale treatability testing.

Although polyelectrolytes are available in both liquid and dry form they are all shipped in relatively small quantities (bags, fibre drums or liquid filled drums) all have basically the same handling and feeding requirements and all are comparitively safe to store and handle. For this reason it is sufficient to specify the equipment required to dissolve (or dilute) and feed these chemicals and leave the actual selection of the appropriate chemical until bench scale treatability tests can be carried out using actual samples of waste.

Secondary Solid Separation/Oil Water Separation

Following coagulation of precipitated inorganic solids and destabilization of oil/water emulsions it is necessary to physically separate the resulting solid/liquid and aqueous/organic phases. A majority of waste treatment applications use one (or more) of the following processes for this purpose:

- o gravity sedimentation
- o vacuum filtration
- o pressure filtration

- centrifugation
- air flotation

Each of these technologies has been described briefly in section 3.7.1 (p. 59) of this report.

The rationale for the selection of the preferred technologies for solids separation and for oil/water separation are summarized in the following sections. Additional backup information is presented in Tables A-3 and A-4 of Appendix A.

Solids Separation

Gravity sedimentation is the preferred method of achieving separation of suspended solids immediately following the precipitation and coagulation processes for the following reasons:

- Gravity sedimentation provides an effective and reliable means of achieving separation of coagulated solids.

- Gravity sedimentation is a suitable and widely used pretreatment step for improving the efficiency of subsequent sludge dewatering steps.

- Precipitation, coagulation and solids separation functions can be combined in one process unit if it is advantageous to do so.

- Equipment requirements are simple, safe to operate and inexpensive.

Oil/Water Separation

Gravity separation in combination with centrifugation and air flotation are the preferred methods of achieving separation of oil, grease and other immiscible organics following emulsion breaking for the following reasons:

- Gravity separation of some of the demulsified oil can be carried out simply and easily in the emulsion breaking tank immediately following the emulsion breaking steps, therefore no additional items of equipment are required.

- The major disadvantage of gravity separation alone is the length of time required to achieve efficient separation (several hours) particularly if the demulsification steps have been only partially effective or the specific gravity of the organic phase is close to that of the aqueous phase. Centrifugation is capable of exerting forces which are several thousand times greater than the forces in gravity separation. This results in greatly increased separation efficiency over a shorter period of time (several minutes).

- Depending upon the type of waste being treated, the aqueous discharge from the centrifuge could require additional treatment to remove residual oil and grease and/or finely divided suspended solids. Dissolved air flotation and precoat filtration (usually vacuum filtration) are two of the most common methods of achieving this treatment objective. Dissolved air flotation has been chosen in favour of precoat filtration for this application for the following reasons:

  - The skimmings from the dissolved air flotation unit are more amenable to subsequent handling and processing steps compared to filter cake materials which contain high concentrations of inert precoat material. The skimmings can either be pumped back to the emulsion breaking tank for further oil recovery or sent directly to the organic tank farm for destruction by incineration whereas the oily filter cake would only be suitable for direct destruction by incineration.

  - air flotation can also be expected to achieve some incidental removals of volatile organic compounds by air stripping during the flotation process. Although a disadvantage of this process is that these organics must then be scrubbed from the ventilation air before it is discharged to atmosphere, a similar problem would exist with fugitive emissions from filter cakes produced by precoat filtration. In both cases hoods or enclosures are required to contain potentially hazardous vapours for removal in the ventilation air scrubbing system.

- Air flotation units are widely used in applications such as this which involve removal of immiscible organics after gravity separation.

Sludge Dewatering

Sludge dewatering is a "required" treatment step in order to minimize the quantity of uncontaminated water which requires solidification and landfilling. Gravity thickening provides an effective and reliable means of thickening sludges prior to dewatering. However, gravity thickening alone is not capable of achieving the highest possible sludge solids concentrations. Alternative mechanical sludge dewatering methods are required to achieve this purpose. The alternatives are as follows:

- o centrifugation
- o plate and frame pressure filtration
- o vacuum filtration
- o belt filtration

As indicated in Table A-5 of Appendix A, pressure filtration is the preferred choice for this application for the following reasons:

- o Plate and frame filters are generally capable of producing the higher cake densities (30 to 40 % by weight), and improved filtrate clarity at reduced chemical consumption compared to alternative methods.

- o Plate and frame pressure filtration is the method of choice at a majority of the regional physical/chemical treatment facilities which are comparable to OWMC's Facility.

- Centrifugation is less suitable for this purpose because of the tendency for the centrifuge to break up the fragile metal hydroxide flocs resulting in high suspended solids concentrations in the centrate (recovered water).

- Vacuum filtration is considered to be less suitable for this purpose because its cake densities tend to be lower (25 to 30 % by weight), they are more costly and more units are required to satisfy the anticipated filtration requirements of this process.

- Belt filters are less suitable for this purpose because they are designed primarily for fibrous, compressible sludges such as sewage and pulp and paper sludges. Belt filters do not perform as well on non-compressible gelatenous sludges such as metal hydroxides.

Other Secondary Treatment Processes

Stripping

Stripping is a process which is used in industry for the removal of volatile organics, hydrogen sulphide and ammonia. Stripping with air is used primarily for the removal of ammonia from waste waters. This operation is normally carried out in packed towers but other configurations are possible including spray ponds and holding ponds with surface agitation.

Steam stripping is basically a fractional distillation process designed to remove volatile components from a waste stream. As such it is usually carried out in either a packed column or tray tower. Steam stripping is primarily used for the treatment of waste waters containing ammonia, hydrogen sulphide and phenol.

The major short comings of stripping technologies which make them unsuitable for inclusion in the preliminary design of the OWMC physical/chemical plant are as follows:

- Air stripping and steam stripping processes would be difficult to optimize for waste streams containing a wide range of volatile and non volatile contaminants.

- Air stripping would require extensive air pollution control equipment to minimize emissions to the atmosphere thus resulting in high capital and operating costs.

- Energy requirements are high for stream stripping compared to alternative processes which are equally capable of removing low concentrations of volatile organics such as activated carbon.

- Steam stripping is worthy of future consideration (after start-up) if it becomes necessary to reduce the loading of concentrated aqueous organic wastes to the incineration plant or, reduce the loading of dissolved organics to the physical/chemical effluent polishing steps.

Solvent Extraction

Solvent extraction is the process whereby selected constituents of a liquid solution can be separated or extracted from the liquid solution by contacting it with another immiscible liquid. In all cases the constituents to be removed must be more soluble in the extracting solvent than in the original solution. The process generally requires three steps: extraction, solvent recovery (eg. by distillation) and, recovery of traces of solvent from the treated stream (eg. by stripping, distillation, adsorption).

For waste water treatment applications solvent extraction is generally applied to the removal of organic contaminants from water using an organic solvent. One of the more common uses of solvent extraction in waste treatment processes is for the removal of high concentrations (greater than 500 ppm) of phenol and related compounds from waste waters. (Patterson[16]; US Environmental Protection Agency[10]). In this case solvents such as light oils, benzene and toluene are commonly used.

Solvent extraction is not considered to be a technology which is suitable for inclusion in the preliminary design of OWMC's physical/chemical treatment plant for the following reasons:

- Solvent extraction is basically a recovery process. The existing waste profile information does not indicate the presence of specific organic contaminants in recoverable concentrations are likely to be present in the wastes requiring physical/chemical treatment.

- The potential suitability of solvent extraction processes are worthwhile examining in detail once a potentially recoverable contaminant has been identified and treatability tests can be carried out to determine its suitability for recovery by solvent extraction methods.

- Processes such as carbon adsorption tend to be more economical for the treatment and dilute waste streams unless the value of the recovered waste is high (Arthur D. Little[12]).

Distillation

Distillation is a process which takes advantage of the fact that the vapour produced by a boiling liquid solution has a different composition than that of the solution itself. Distillation is therefore accomplished by boiling a liquid solution and condensing the vapour. The equipment required for this purpose is expensive, complex and therefore requires extensive operator training.

Distillation is not considered suitable for inclusion in the preliminary design of the physical/chemical treatment plant for the following reasons:

- Distillation processes can not be operated efficiently in a start up and shutdown mode and therefore does not conform to the 8 hour per day, 5 day per week batch treatment mode of operation of the physical/chemical treatment plant.

- The OWMC waste profile information is insufficient to indicate whether an organic solvent recovery step (such as distillation) is warranted based on the economics of resource recovery and recycle. The present European experience would indicate that high heating value organics such as waste oils and solvents are in demand at similar hazardous wastes incineration facilities elsewhere to minimize the requirements for auxiliary fuel for the destruction of more dilute organic wastes. Although a distillation step may be useful to upgrade the heating value of dilute aqueous organic wastes prior to incineration, this process has been excluded from further process development until actual operating waste profile information provides definitive justification for adding this process to OWMC's treatment Facility.

3.7.3 EFFLUENT POLISHING

The remaining potentially suitable technologies listed on p. 45 are considered to be potentially suitable as final effluent polishing steps. As indicated in Section 3.6.1 (p. 50) the preferred effluent polishing technologies have been selected for their ability to remove the widest possible range of organic, inorganic and suspended contaminants to the lowest possible levels following pretreatment by oxidation, reduction, precipitation, coagulation and separation techniques discussed in the previous sections. The purpose of the effluent polishing steps is to produce a treated effluent which is suitable for reuse on site or discharge by evaporation.

Polishing steps were therefore selected for evaluation based on their capabilities for:

- removal of residual colloidal suspended solids and emulsified oil and grease,
- removal of residual dissolved heavy metal cations and toxic or nuisance causing anions (such as nutrients),
- reduction of overall total dissolved solids levels in treated effluents, and
- removal of residual dissolved organics.

The following alternative technologies have been evaluated for their ability to provide the desired degree of effluent polishing.

- Residual suspended solids removal
  - ultrafiltration
  - microscreening
  - granular media filtration
- Removal of dissolved organics
  - ultrafiltration
  - carbon adsorption
  - resin adsorption
  - biological treatment
- Removal of dissolved inorganics
  - reverse osmosis
  - evaporation
  - electrodialysis
  - ion exchange
  - liquid ion exchange

Particular emphasis has been given to environmental factors relating to criteria such as performance, safety, flexibility and reliability in determining the preferred combination of effluent polishing steps since it is these criteria which ensure that OWMC's objectives regarding protection of human health and the environment are satisfied.

Residual Suspended Solids Removal

Ultrafiltration

Ultrafiltration is a membrane separation process which can achieve separation of high molecular weight dissolved components and/or colloidal suspensions of particles which are difficult to separate by other methods. In ultrafiltration, a concentrated reject stream is collected from the upstream high pressure (70 to 700 kPa) side of a semi permeable membrane and a clean permeate stream is collected from the downstream side of the membrane. Ultrafiltration membranes are very similar to reverse osmosis membranes except they have larger pore sizes compared to reverse osmosis membranes. This means that reverse osmosis membranes are not only able to remove lower molecular weight organic compounds compared to ultrafiltration membranes but they are also able to remove dissolved inorganic ions such as dissolved heavy metals and soluble salts which ultrafiltration membranes can not.

Ultrafiltration has been used primarily for processing various types of waste emulsions such as waste cutting and grinding oils, waste oils from steel rolling mills, animal oils, alkaline degreasing baths and latex wastes as well as for removing finely divided suspended solids.

For filtration purposes ultrafiltration has been rejected in favour of granular media filtration for the reasons outlined on p. 101.

Microscreening

Microscreening is a physical separation process which consists of a motor driven rotating drum mounted horizontally in a rectangular chamber. A fine screening media covers the periphery of the drum. Feedwater enters the drum interior through the open end and passes radially through the screen. Suspended solids in the feed are deposited on the inner surface of the screen. Pressurized water jets are used to wash the inner surface of the screen to remove the mat of deposited solids. Microscreening has been used to replace secondary settling tanks in biological treatment applications and to remove algae from uncoagulated lagoon effluents (US Environmental Protection Agency[35]).

Granular Media Filtration

Granular media filtration has been described briefly in section 3.7.1 (p. 62) of this report. Filters of this type are primarily used to produce a purified stream containing low suspended solids concentrations, typically less than 10 mg/L suspended solids. Granular filters are frequently installed downstream of sedimentation processes. In many cases they are used as the final step in the waste treatment process prior to discharging the treated effluent.

Granular media filtration will not perform as well as ultrafiltration for certain types of waste, for example in removing extremely small suspended particles or high molecular weight dissolved organics. However, it is proven to be capable of fulfilling the requirements of this stage of the treatment process, that is to remove residual oil and grease and suspended solids concentrations which could be present in the partially treated waste after secondary treatment. Furthermore, as indicated in Table A-6 Appendix A granular media filtration has a number of other advantages relating to its flexibility and reliability compared to ultrafiltration and microscreening which make it the preferred choice for this particular application.

- Granular media filtration is more widely used and therefore better proven than ultrafiltration or microscreening for this application.

- Ultrafiltration will likely require pilot scale testing to confirm the optimum membrane type for this particular application whereas granular media filtration is so well proven and widely used for this purpose that pilot testing would not be required.

- Granular media filtration is much less prone to upset conditions and is generally easier to restore to normal operation after an upset by repeated backwashing or by replacing the filtration media. This can be done easily and inexpensively with readily available materials. By comparison, severely plugged ultrafiltration membranes may have to be replaced. Due to the specialized nature of these membranes, this would be a comparatively expensive operation.

Removal of Dissolved Organics

As indicated in Section 3.6.1 (p. 50) of this report, although the primary function of the physical/chemical treatment system is to treat inorganic wastes, it will be necessary to include one or more polishing steps in order to remove residual dissolved organic contaminants from the partially treated effluent prior to discharge or reuse.

The following general characteristics are expected to apply to the partially treated waste after primary treatment, secondary treatment and filtration.

- The partially treated wastes will be stored in batches of 40 m^3 or less.
- The pH of the partially treated wastes will vary from batch to batch over a range from approximately pH 7 to 10.5.
- The concentrations of residual suspended solids and immiscible oil and grease are expected to be less than 10 mg/L.
- Total dissolved solids (TDS) concentrations will vary considerably from batch to batch. Effluent quality data from HIM physical chemical treatment facility in Frankfurt, West Germany indicate that after primary and secondary treatment, effluents can be expected to contain TDS concentrations ranging from 1 to 8 % by weight with an average of 4.5 to 5 % by weight.
- The concentrations of dissolved organics will vary widely from batch to batch from almost zero to perhaps as much as 1 to 2 % by weight. A majority of those batches of inorganic waste which do

contain residual dissolved organics after primary and secondary treatment are expected to contain concentrations significantly less than 1 % by weight (10 000 mg/L).

- The types of dissolved organics which remain in the partially treated waste are also expected to vary considerably from batch to batch depending upon the type of waste being treated and the extent to which the concentrations of various organics have been reduced by primary and secondary treatment processes such as chemical oxidation, precipitation, coagulation and sedimentation.

The above mentioned factors have had an influence in the selection of the preferred combination of effluent polishing steps.

The following generic processes have been evaluated as alternatives for the removal of residual dissolved organics:

- ultrafiltration
- carbon adsorption
- resin adsorption
- biological treatment processes

Ultrafiltration

Ultrafiltration has been discussed briefly in the previous section (p.100) in the context of its suitability for use as a polishing filtration technology. As indicated, ultrafiltration is also capable of separating dissolved high molecular weight organics from aqueous waste streams. It has been noted that ultrafiltration is very similar in concept to reverse osmosis except that reverse osmosis is capable of removing a much wider range of dissolved organic contaminants as well as dissolved inorganic contaminants such as salts and heavy metals due to the smaller pore size of the reverse osmosis membrane. In view of the relative capabilities of ultrafiltration and reverse osmosis and the fact that reverse osmosis has been selected as the preferred treatment method for removing dissolved inorganics, partly because of its capability for removing dissolved organics as well, ultrafiltration has been eliminated from further consideration at the present time.

Carbon Adsorption

Carbon adsorption is a physical/chemical treatment process which uses "activated" carbon to adsorb contaminants which are dissolved in a liquid waste stream. Adsorption on activated carbon occurs when a molecule in a liquid solution comes in contact with the surface of the activated carbon and held there by physical and/or chemical forces. The term "activated" carbon applies to any amorphous form of carbon which has been specially treated by a process of dehydration, carbonization and oxidation to yield a product which has a high capacity for adsorption due to its extremely high ratio of surface area to volume.

Activated carbon is currently in widespread use in full scale industrial waste treatment applications for the treatment of a wide variety of organic and inorganic contaminants. In general, organics which have a high molecular weight, low water solubility, low polarity and low degree of ionization are most effectively adsorbed. For example, pesticides, polychlorinated biphenyls, polynuclear aromatic compounds, phthalates, aromatic, and substituted aromatic compounds are strongly adsorbed on activated carbon. Highly soluble organics such as glycols, soaps and alcohols (eg. methanol and ethanol) are least effectively adsorbed (Arthur D. Little[12]).

One additional feature of activated carbon adsorption is that biological activity will usually take place in a carbon bed. This usually occurs after a number of hours of operation once the bacterial population has developed and become acclimated. If the adsorbed organics are biodegradable, non-toxic and present in sufficient concentrations in the carbon bed, biological degradation can significantly increase the removal capacity of the carbon by extending its adsorption life (Arthur D. Little[12]).

Giusti et al[21] has summarized the treatability of a large number of organic compounds by activated carbon including alcohols, aldehydes, amines, aromatics, esters, glycols and glycol ethers, ketones and organic acids. These data indicate that virtually all organic compounds are removable to varying degrees by activated carbon.

Arthur D. Little[12] has documented a large number of full scale industrial waste treatment applications which use activated carbon for the treatment of organic chemical wastes. Many of the types of organics and organic indicators currently being treated by activated carbon are similar to those which could be present in wastes which are likely to be amenable to physical/chemical treatment including phenols, chlorinated phenols, toluene, resins and dyes, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Table A-7 in Appendix A compares carbon adsorption with alternative methods of removing residual dissolved organics. As indicated in Table A-7, activated carbon has a number of advantages over alternative technologies which make it the preferred choice for inclusion in the preliminary design of the physical/chemical treatment system. These are: (Ref: Arthur D. Little[12])

- High organics removal.

- Applicability to a wide variety of organics including toxic organics such as PCB's and pesticides which are resistant to biological degradation.

- Capability for inorganics removal (eg. cyanide, chromium and others).

- High flexibility (eg. rapid start up and shutdown).

- Low sensitivity to feed variations (flow rate or concentration).

- Insensitivity to toxic materials.

- Minimum space requirements.

- Organics are ultimately destroyed (by incineration of spent carbon onsite or thermal regeneration offsite).

Resin Adsorption

Resin adsorption is a process which utilizes synthetic polymeric resins to adsorb organics from liquid solutions. The resins consist of small, hard insoluble beads (20 - 50 mesh size) of polymeric material through which the contaminated waste water is passed. Resin adsorption is similar to granular activated carbon adsorption except that due to the high cost and specialized nature of the synthetic resins they are always regenerated, usually by means of organic solvents or caustic.

The detailed comparison of resin adsorption versus alternative methods of removing residual dissolved organics from liquid waste streams is given in Table A-7 of Appendix A.

The major reasons why resin adsorption has been rejected in favour of activated carbon adsorption are as follows:

- Resin adsorption is less widely used for waste treatment applications compared to carbon adsorption.

- Due to the comparative lack of operating experience with resin adsorption systems in hazardous waste treatment applications, considerable pilot scale treatability testing would likely be required to select the appropriate resin(s) for this particular application.

- Additional processing steps are required to recover and recycle the regenerant solvent.

Biological Treatment Processes

Biological treatment processes involve placing a waste stream in contact with a mixture of microorganisms, so that the organic compounds in the waste stream are decomposed. Biological processes optimize the microbial environment, so that natural degradation is enhanced. Methods for optimizing biological degradation include controlling the dissolved oxygen level, adding nutrients, increasing the concentration of microorganisms, and slowly increasing influent waste concentrations so that an acclimated microbial population develops within the process. (Arthur D. Little[12]).

Biological treatment is applicable to aqueous waste streams with organic contaminants. The organics can be either dissolved or suspended in the influent waste stream to be amenable to biodegradation. Water is essential to the treatment process. The microorganisms rely on enzymes to catalyze organic decomposition reactions, and the enzymes require water to remain active. In aerobic biological treatment processes, both simple and complex organics can eventually be decomposed to carbon dioxide and water or to lower molecular weight organics. Oxygen is essential to the decomposition of long chain and aromatic hydrocarbons. In anaerobic biological treatment processes, only simple organics such as carbohydrates, proteins, alcohols, and acids can be decomposed. (Arthur D. Little[12]).

Biological treatment processes do not alter or destroy inorganics. In fact, at higher concentrations soluble inorganics such as dissolved salts and heavy metals inhibit biological activity. Trace concentrations of inorganics may be partially removed from the liquid waste stream during the biological treatment, because of adsorption onto the microbial cell coating. Anionic species, such as chlorides and sulphates, are not affected by biological treatment. (Arthur D. Little[12]).

The treated effluents from biological treatment processes will contain dissolved inorganics which are not adsorbed by the biomass sludge plus non volatile, refractory compounds which are not easily decomposed by biological activity or susceptible to being stripped from the waste water by the effects of aeration.

Biological treatment methods can take a number of forms. The most commonly used of these are:

- activated sludge
- trickling filters
- rotating biological contactors
- fluidized bed
- waste stabilization ponds
- aerated lagoons
- composting
- land farming
- anaerobic digestion
- powdered activated carbon
- sequencing batch reactors

There are a number of factors which will influence the extent to which any of the above-mentioned biological processes are capable of achieving maximum removals of organic contaminants on a consistent basis. These are:

- the types of organic contaminants present in the waste stream,
- the concentrations of each of the various types of organics,
- the presence of other components in the waste which may inhibit biological activity eg. dissolved salts and residual heavy metals,
- the extent to which the microbial population has been acclimatized to the waste being treated, and
- the length of time during which biological oxidation is allowed to take place.

Although the various types of biological processes vary somewhat in their ability to enhance the rate and efficiency of biological decomposition of organics, all biological processes rely on the natural functions of living organisms as the primary mechanism of treatment.

Therefore all biological treatment processes will be affected by the factors outlined above. With this in mind, biological treatment has been evaluated as a generic processing technology in terms of comparing biological methods with alternative physical/chemical methods for removing residual organics. The results of this comparison are summarized in Table A-7 of Appendix A.

As indicated in Table A-7 activated carbon adsorption is the preferred choice for inclusion in the conceptual design of the physical/chemical treatment plant. Carbon adsorption has been selected for the reasons outlined on p. 105. Biological treatment has instead been identified as a potentially suitable technology for future consideration after OWMC's Facility has been in operation for a period of time, when the waste profile characteristics are known more precisely and when actual samples of waste are available for treatability testing. The reasons for this are as follows:

- Biological treatment methods are less well suited than activated carbon for the treatment of highly variable types and concentrations of organic contaminants. Until actual operating data are available to indicate otherwise, the conservative approach is to assume that the types and concentrations of organic contaminants in batches of inorganic waste being treated in the physical/chemical plant will be highly variable (and unpredictable) from batch to batch and highly toxic toward microorganisms. The use of activated carbon (in combination with reverse osmosis), supported by incineration can be expected to provide greater consistency and reliability under these operating conditions compared to biological treatment methods.

- In order to minimize the potentially adverse effects of highly variable feed characteristics on biological treatment systems it would be necessary to include a pretreatment equalization step. This approach is contrary to the operating philosophy which has been adopted for the physical/chemical plant which is aimed at maximizing the extent to which batches of waste are kept segregated during the physical/chemical treatment process. As indicated in Section 2.5 (p. 14), this approach has been adopted to minimize the volume of individual batches of waste which may require retreatment or treatment by alternative methods (such as incineration) in the event that physical/chemical treatment methods fail to achieve the desired effluent quality. As batch sizes become larger, it becomes less practical and more costly to incinerate those batches which fail to meet the desired treatment objective due to a high residual concentration of dissolved organics.

- The rates of biodegradation tend to be slower and the acclimation periods longer for many of the more environmentally sensitive priority pollutants such as chlorinated aliphatics, PCB's, pesticides and polynuclear aromatic compounds. These compounds tend to be the most strongly adsorbed by activated carbon.

- A large number of possible equipment configurations and operating parameters must be optimized in order to design a biological treatment system which will produce consistent and reliable results on the types of wastes which could require treatment in the physical/chemical plant. Therefore, it is imperative that extensive treatability tests be carried out to determine the suitability of various biological treatment methods in the context of the types of wastes actually being received for treatment in the physical/chemical process area, the capabilities of the other physical/chemical treatment steps and the capabilities of the other process areas (i.e. incineration).

- Making provision for the future addition of biological treatment will enable the need for such a system to be adequately assessed and its design and operation optimized without jeopardizing the reliability of the physical/chemical treatment systems for achieving the desired effluent quality on a consistent basis.

Activated sludge treatment either alone or in combination with powdered activated carbon or the sequencing batch reactor are the two biological treatment techniques which would appear to be best suited to this application for the reasons outlined in the following sections:

Activated Sludge processes involves mixing the waste with air and biological sludge (microbial floc) in an aeration tank which is normally sized to provide a hydraulic retention time of approximately 6 to 8 hours. The mixed liquor which is discharged from the aeration tank is allowed to settle in a secondary clarifier. A portion of the settled sludge (20 - 30%) is returned to the aeration basin to maintain a high population of microorganisms in the tank. The excess sludge is withdrawn from the secondary clarifier for disposal. There are basic modifications of the basic activated sludge process such as tapered aeration, step aeration, complete mix, contact stabilization, extended aeration and systems which employ pure oxygen for aeration instead of air.

Activated sludge systems possess several features which make them attractive for future consideration:

- They are relatively compact compared to other methods of biological treatment.
- They have the capability for treating wastes with higher influent BOD loadings because of their high microbial population densities.
- Over a period of time they will acclimatize to potentially toxic components which are regularly present in the influent waste.

Powdered activated carbon/activated sludge processes have been investigated in recent years for their ability to improve the performance of conventional activated sludge systems. In this process powdered activated carbon (200 to 300 mesh)is added either directly to the aeration tank of a conventional activated sludge treatment system or mixed with the influent prior to entering the aeration tank. The activated carbon/sludge solids mixture is recycled and wasted from the secondary clarifier in much the same way as the conventional activated sludge system.

Powdered activated carbon/activated sludge systems have been shown to be capable of improving the performance of conventional activated sludge systems with respect to:

- reducing effluent biochemical oxygen demand, chemical oxygen demand, total organic carbon and suspended solids concentrations from conventional activated sludge systems,
- increasing the stability of plant operation by providing additional protection to the biological treatment system to shock loads,
- eliminating the necessity of adding a separate granular activated carbon treatment capability to polish biologically treated effluents, and
- reducing the operating costs for granular activated carbon systems.

A number of important designs and operating parameters must be determined and optimized in order to arrive at a suitable design for powdered activated carbon/activated sludge systems. These include:

- establishing the total quantity of inorganic waste which is likely to be amenable to biological treatment,
- determining the type and concentration of organics which must be removed,
- establishing the optimum hydraulic and sludge retention times for the system, and
- establishing the optimum dosage and type of powdered activated carbon.

This technology has therefore been selected for future consideration due to the potential for powdered activated carbon/activated sludge treatment to reduce the consumption of granular activated carbon and thereby improve the efficiency of the effluent polishing steps.

The **sequencing batch reactor** is a batch treatment process which is essentially a fill and draw activated sludge system (Arora et al[22]). A full scale sequencing batch reactor (SBR) system is currently in operation for the treatment of hazardous wastes (primarily landfill leachates) at the CECOS International wastewater treatment plant in Niagara Falls, N.Y. The design and construction of the full scale facility at CECOS followed approximately one year of pilot plant studies to develop process design and performance data for this system. (Herzbrun et al[23]).

The sequencing batch reactor system consists of a single (or multiple) reaction tank(s) each of which accomplishes treatment, sedimentation of mixed liquor solids and withdrawal of supernatant in the same tank. this eliminates the need for separate clarifiers and sludge recycle pumps. The major advantages of sequencing batch reactor systems which make them potentially suitable for use at OWMC's proposed Facility are as follows:

- The batch treatment mode of operation is consistent with that of the remainder of the physical/chemical plant.

- One or more of the existing chemical reaction tanks in the plant could be used to carry out full scale evaluations on actual samples of waste after start-up.

- SBR systems offer substantial process flexibility
  - reaction times can be varied to ensure that effluent meets specified requirements,
  - settling times can be varied to maximize solids separation efficiencies, and
  - system design capacity can be varied by varying the fraction of the SBR tank capacity used.

For these reasons the SBR has been selected for future consideration in the physical/chemical plant.

The remainder of the more commonly used biological treatment methods listed at the beginning of this section are considered to be suitable for serious future consideration only after activated sludge or powdered activated carbon/activated sludge and sequencing batch reactor systems have been investigated and ruled out.

Trickling filters are biological treatment processes which allow the wastewater to trickle through a bed of rock or other packing. The microbial population attaches itself as a fixed film to the packing. The major disadvantage of trickling filters which make then potentially less suitable for this application is that their final effluent quality is generally not as good as that from activated sludge plants because of their comparitively short residence times (Proctor & Redfern[1]). This disadvantage would likely be exaggerated for some of the more toxic organic compounds which tend to be more resistant to biological degradation.

Rotating biological contactors are also fixed film reactors in which the biological growth is attached to a series of rotating discs which are partially submerged in the waste. The rotating biological contactor configuration is somewhat less susceptible to upsets from fluctuations in hydraulic loads, organic concentrations and toxic shock loads compared to activated sludge systems because of its shorter retention time and large microbial population. However, because of this short retention time, short term increases in toxic organics are more likely to pass through the system without treatment.

Fluidized bed systems are a third type of fixed film biological treatment system in which the microbial population attaches itself to inert particles such as sand. The sand particles with their attached biological growth are kept in suspension (fluidized) by the upward flow of waste through the bed. The major advantage of fluidized bed systems over other fixed film or suspended growth biological systems is their very large surface area to volume ratio which permits these systems to operate at organic loadings compared to most other biological treatment systems. Fluidized bed systems operate best at constant high organic loadings (Proctor & Redfern[1]). For this reason they are not expected to be well suited for this particular application.

Aerated lagoons and **waste stabilization ponds** are designed to enable biological treatment to take place outside in ponds usually constructed from earthen dams. Stabilization ponds are mixed or aerated naturally by wind currents. Aerated lagoons are equipped with either mechanical surface aerators or diffused air (sprayers). Due to their large size these systems are constructed outdoors. Neither of these processes are particularly well suited to this particular application for the following reasons:

- The performance of any outdoor unheated biological treatment system will be adversely affected by the effects of low temperatures during the winter months.

- Quality control of treated effluents and the ease with which batches are able to be retreated or incinerated in the event of an upset condition would be extremely difficult due to the large hydraulic capacity of these systems.

Composting and **Anaerobic Digestion** are both sludge treatment processes which are not suitable for dilute aqueous wastes containing residual dissolved organics.

Landfarming is a procedure which relies on the natural bacterial populations in soil to biologically degrade municipal sludges and some liquid industrial sludges (for example oil refinery sludges) by spreading this material over large areas of land. This technology is not considered to be applicable to OWMC's Facility for the following reasons:

- The large land areas normally required.

- The adverse public perception associated with spreading "hazardous" wastes over large areas of land for treatment purposes.

- Potential odour problems associated with this practice.

- The reduced efficiency of degradation during the winter months.

Removal of Dissolved Inorganics

As indicated in Section 3.6.1 (p. 50) polishing steps will also be required to remove residual concentrations of heavy metal cations, nutrients (nitrate and phosphate), fluoride, cyanide (primarily ferrocyanide or ferricyanide)in order to achieve the lowest possible levels of residual dissolved inorganics in the treated effluents. In addition, it will be necessary to reduce the concentrations of other non-toxic dissolved solids such as sodium, calcium, sulphate, chloride and carbonate in the treated effluent to further improve the suitability of the treated effluent for on site reuse.

The following general characteristics are expected to apply to the partially treated waste after primary treatment, secondary treatment and polishing by filtration and activated carbon adsorption.

- The total dissolved solids concentrations will vary widely from batch to batch from less than 1 % by weight to perhaps as high as 8 % by weight. A majority of these dissolved solids will consist of carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium and potassium with traces of heavy metals.

- The concentrations of dissolved organics will be low. Some batches of waste could contain residual concentrations of dissolved organics which have not been removed by previous secondary treatment and polishing steps.

In view of these considerations, a final effluent polishing step has been chosen first for its ability to remove high total dissolved solids concentrations and secondly for any associated benefits which may be obtained in terms of achieving the lowest possible levels of dissolved organics in the final treated effluent. Alternative technologies considered for the removal of total dissolved solids are:

- reverse osmosis
- evaporation
- electrodialysis
- ion exchange
- liquid ion exchange

The results of these evaluations are summarized in Table A-8 Appendix A. Reverse osmosis and evaporation are the preferred methods of achieving this treatment objective for the reasons outlined in the following sections:

Reverse Osmosis

Reverse osmosis is a membrane separation process which has been in use for many years for the production of potable (drinking) water from sea water containing 30 000 to 35 000 mg/L of total dissolved solids. However, because of its ability to treat aqueous solutions containing both dissolved organic and inorganic contaminants reverse osmosis has found increasing use in waste treatment and water purification applications and for concentrating electroplating rinsewaters for reuse to recover valuable heavy metals.

Reverse osmosis employs a semi-permeable membrane and high pressure to separate dissolved inorganic and organic components from aqueous solutions. The major difference between reverse osmosis and ultrafiltration is that reverse osmosis membranes are capable of rejecting (or concentrating) much smaller molecules and ions thereby achieving an overall reduction in dissolved solids and heavy metals in addition to reducing the concentrations of the higher molecular weight organics which are capable of being removed by ultrafiltration.

Evaporation

Evaporation is a process for concentrating solutions or slurries by the additions of heat to vapourize a portion of the liquid. Evaporation is usually carried out in equipment designed specifically for this purpose such as multi-effect, vapour compression, multi-flash systems or evaporative driers (Proctor & Redfern[1]). The vapour produced by evaporation can either be discharged directly or condensed to produce a liquid effluent for discharge or reuse.

Reverse osmosis has been selected as the preferred method for removing residual heavy metals and total dissolved solids from the partially treated effluents in the physical/chemical plant. In addition, evaporation has been chosen to augment the capabilities of reverse osmosis and to provide a means of discharging excess treated effluent which cannot be reused on site. Although the capabilities of these two processes overlap somewhat with respect to removing moderate to low concentrations of total dissolved solids, these processes have a number of complementary features relating to performance, flexibility and cost which justify including both of these processes in the physical/chemical process design. The reasons for these choices are summarized as follows:

- Reverse osmosis units are capable of providing very effective treatment of streams which contain total dissolved solids (TDS) concentrations of up to 3 to 4 % by weight. Due to the more energy intensive nature of evaporation processes, reverse osmosis is the most cost effective method of polishing partially treated effluents in this concentration range.

- Effluent TDS data from the HIM Facility in Frankfurt, West Germany have indicated that the TDS in their treated effluent averages approximately 4.5 to 5 % by weight and ranges from approximately 1 to 8 % by weight. Total dissolved solids analysis of 42 treated effluent samples from the HIM Facility have shown the following split in TDS values:

- 12 samples (28%) had TDS values less than 4 % by weight
- 18 samples (44%) had TDS values between 4 and 5 % by weight
- 12 samples (28%) had TDS values greater than 5 % by weight.

Overall mass balance calculations based on OWMC's waste profile data have indicated that approximately 50% of the total typical effluent from the physical/chemical treatment processes are expected to contain TDS concentrations in excess of those which can be practically handled by reverse osmosis (i.e. above approximately 3.5 % by weight TDS). Evaporation is the only available process which can handle these very high TDS concentrations. Evaporation has therefore been chosen to augment the capabilities of reverse osmosis and provide the physical/chemical treatment system with sufficient flexibility to handle the complete range of TDS concentrations expected. This approach will minimize the total quantity of residues which will require solidification and landfilling thereby minimizing environmental impacts and maximize the total volume of treated effluent available for recycling.

- Although the primary treatment function of reverse osmosis is to remove dissolved inorganic salts including residual heavy metals, reverse osmosis is also capable of removing trace concentrations of toxic organics (such as the US Environmental Protection Agency list of organic priority pollutants) which are not removed by activated carbon. Batches of reverse osmosis rejects which are high in organics can be routed to the incinerator for disposal. Evaporators on the other hand are not well suited to concentrating organic contaminants. Even moderately volatile organics will report to the vapour phase and either be discharged to the atmosphere or reappear in the evaporator condensate. Reverse osmosis therefore provides additional capability for removing dissolved organic contaminants of concern at the final stages of effluent polishing. This capability would not be available if evaporation alone were chosen as the final effluent polishing step.

- Reverse osmosis is well suited to batch treatment methods involving relatively small batches of waste treated over an 8 hour operating day. This is consistent with the preferred mode of operation for the physical/chemical plant. By restricting the role of the evaporator as a processing step to only those batches of waste which contain the highest TDS concentrations, it will be possible to maintain batch treatment concepts wherever possible within the physical/chemical plant. This approach is designed to produce maximum treatment consistency and reliability.

- In addition to extending the processing flexibility and reliability of the physical/chemical treatment system, evaporation is also the preferred effluent disposal option which eliminates the need to discharge excess treated effluent from the Facility by truck or pipeline. The selection of evaporation as the preferred effluent disposal option is more fully discussed in the Facilities Description (Ref: Monenco[5]).

Electrodialysis

Electrodialysis is also a membrane separation process. In this case the separation of dissolved components of an aqueous stream across a semi-permeable membrane is brought about by the action of an electric field which causes positive and negative ions in solution to migrate in opposite directions. The system relies on alternating cation-permeable and anion-permeable membranes to achieve the required separation.

Electrodialysis has been rejected in favour of reverse osmosis and evaporation for the following reasons:

- Electrodialysis is most suitable for streams containing dissolved solids concentrations ranging from 200 to 5000 mg/L (Arthur D. Little[12]) whereas reverse osmosis and evaporation can handle aqueous streams with total dissolved solids of up to 100 000 mg/L or more.

- The practical lower limit of total dissolved solids in the purified streams from full scale electrodialysis systems is limited by the low electrical conductivity of the product water (to about 250 -

500 mg/L). Reverse osmosis systems are capable of product water with total dissolved solids as low as 5 mg/L (Arthur D. Little[5]). This is ideal for use as incinerator flue gas scrubber make-up water.

- Electrodialysis has no effect on dissolved organics.

Ion Exchange

Ion exchange is primarily used for the removal of inorganic ionic species from aqueous solutions. The process involves contacting the liquid solution with a synthetic ion exchange "resin" which has the capability of exchanging or substituting ions associated with the resin for those which are dissolved with the liquid solution. The chemical nature of ion exchange resins is such that these reactions are reversible thus allowing the resins to be regenerated (usually with strong acids or strong bases) whenever the exchange capacity of the resin becomes depleted. For a more complete description of ion exchange processes and equipment the reader is referred to Arthur D. Little[12] and Proctor & Redfern[1].

Ion exchange has been rejected in favour of reverse osmosis as a final effluent polishing step for the removal of total dissolved solids including heavy metals for the following reasons:

- The upper concentration limit for total dissolved solids in the feed to ion exchange units is about 10 000 to 20 000 mg/L. However, the upper concentration limit of exchangeable ions for efficient operation of ion exchange units is about 2500 mg/L (Arthur D. Little[12]). As such, the total dissolved solids concentrations in some batches of waste are expected to exceed this value by a considerable margin.

- Ion exchange requires the use of virgin chemicals (usually strong acids and alkalis) for regeneration. These streams require further treatment prior to final disposal by solidification.

- Ion exchange processes are generally better suited to the selective removal of specific contaminants from a waste stream using a resin which has been chosen specifically for the purpose rather than for a broad range of inorganics including low concentrations of heavy metals and high concentrations of soluble salts.

Liquid Ion Exchange

Liquid ion exchange is a process which can be used for the selective removal of free and complexed metal ions and other inorganic species from aqueous streams via transfer to an immiscible solvent. In principle this process is the same as the solvent extraction process discussed in Section 3.7.2 (p. 96) for the removal of organics from waste streams except that liquid ion exchange solvents are selected specifically for their ability to remove dissolved inorganic species (mainly heavy metals). Some examples of the types of organic solvents used in liquid ion exchange processes are:

- secondary and tertiary amines
- ketones eg. methylisobutylketone
- ethers eg. chloropropylether
- carboxylic acids
- sulphonic acids
- kerosene
- aromatic solvents
- chlorinated solvents

Liquid ion exchange has been rejected in favour of reverse osmosis for the following reasons:

- The extracted aqueous phase will contain small amounts (5 - 50 mg/L) of the extraction solvent. Many of these solvents are in themselves hazardous or toxic and must subsequently be removed from the treated waste prior to final discharge (Arthur D. Little[12]).

- Liquid ion exchange processes are not suited to the removal of overall total dissolved solids.

CHAPTER 4

SYSTEM DESIGN AND OPTIMIZATION

4.1 INTRODUCTION

Previous sections of this report have described the methodology and rationale for selecting individual physical/chemical treatment technologies for inclusion in the conceptual design of the physical/chemical treatment plant.

The following sections describe how these preferred treatment technologies have been combined into treatment systems and the measures taken to optimize the design and operation of these systems to ensure that the required performance, safety, flexibility and reliability is achieved in a cost effective manner.

4.2 DESCRIPTION OF SELECTED PHYSICAL/CHEMICAL TREATMENT SYSTEMS

As indicated in Section 2.5 (p.10), the physical chemical treatment plant will be required to treat three categories of wastes:

- Inorganic waste
- Aqueous/organic waste
- Miscellaneous waste

A description of the specific types and quantities of wastes which will comprise each of these three general categories has been summarized in Table 2 (p. 12). Due to the particular characteristics and treatment requirements of the inorganic, aqueous/organic and miscellaneous wastes, the physical/chemical treatment plant has been designed with three distinct process treatment systems. Each treatment system is capable of carrying out the following fundamental stages of treatment:

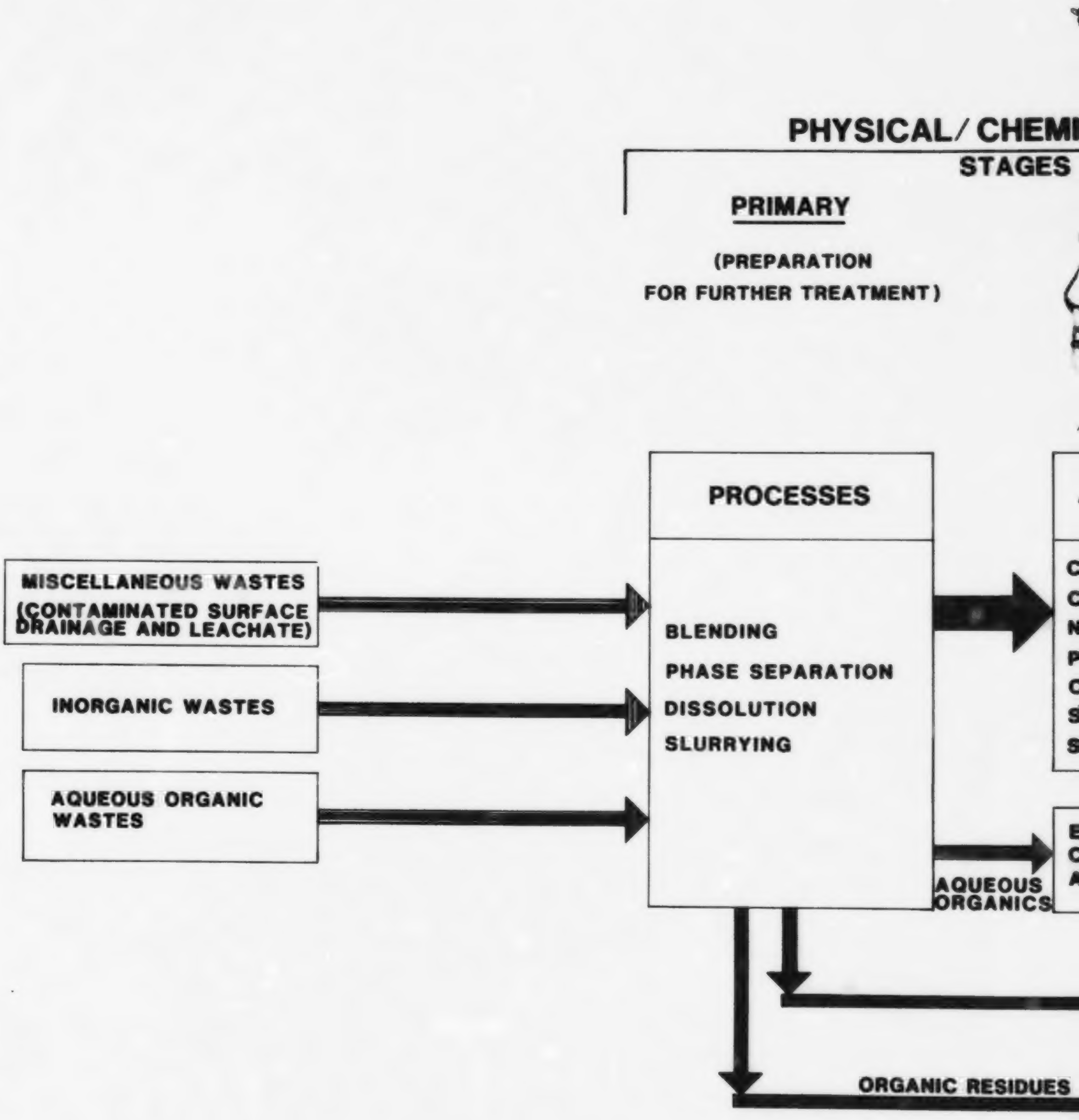
- Primary treatment
- Secondary treatment
- Effluent polishing

Figure 1 provides a schematic illustration of the manner in which the selected physical/chemical treatment technologies have been arranged in stages to enable each category of waste to be treated to the maximum extent possible prior to reuse or discharge. Figure 1 also illustrates the interrelationships between the physical/chemical plant and the solidification and incineration plants.

The following paragraphs describe the particular characteristics and treatment requirements of the inorganic, aqueous/organic and miscellaneous wastes which have led to the development of separate process systems to deal with these wastes at OWMC's Facility.

4.2.1 INORGANIC WASTE TREATMENT SYSTEM

A majority of the wastes which will require treatment in the physical/chemical plant will be predominantly inorganic in nature. Therefore, the inorganic process system will be the main treatment system in the physical/chemical plant. The inorganic treatment system has been designed to treat up to 80 000 t/a (320 t/8 h) of inorganic wastes in batches of up to 40 m^3 in size based on an 8 hour shift per day (250 days/year). This will enable the system to handle 50 000 t/a of inorganic special wastes per 8 hour shift, 5 days per week, 50 weeks per year, and provides additional capacity for:


PHYSICAL/ CHEMI
STAGES
PRIMARY
(PREPARATION FOR FURTHER TREATMENT)
PROCESSES
MISCELLANEOUS WASTES (CONTAMINATED SURFACE DRAINAGE AND LEACHATE)
INORGANIC WASTES
AQUEOUS ORGANIC WASTES
BLENDING
PHASE SEPARATION
DISSOLUTION
SLURRYING
AQUEOUS ORGANICS
ORGANIC RESIDUES

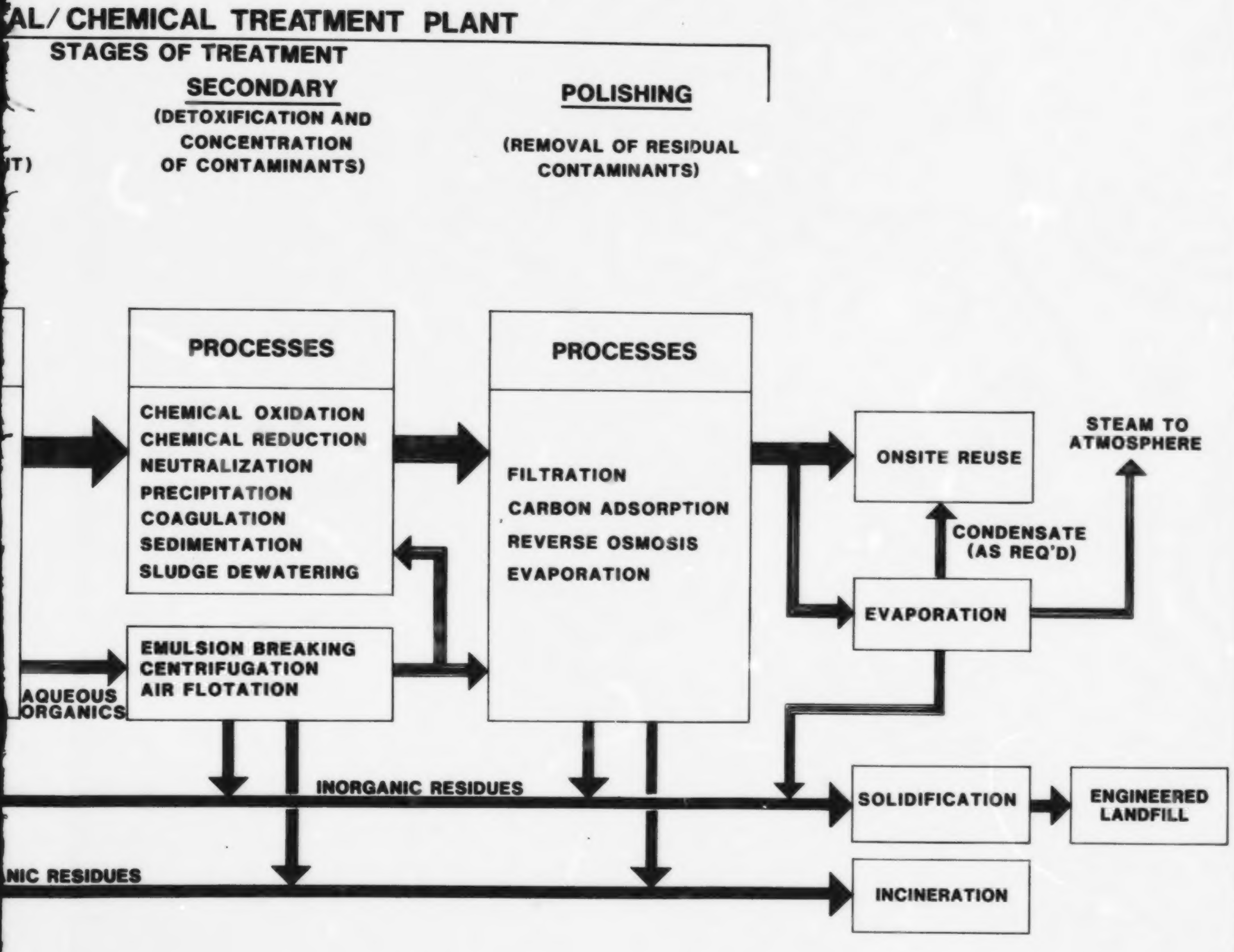

AL/CHEMICAL TREATMENT PLANT
STAGES OF TREATMENT
SECONDARY
(DETOXIFICATION AND CONCENTRATION OF CONTAMINANTS)
POLISHING
(REMOVAL OF RESIDUAL CONTAMINANTS)
IT)
PROCESSES
CHEMICAL OXIDATION
CHEMICAL REDUCTION
NEUTRALIZATION
PRECIPITATION
COAGULATION
SEDIMENTATION
SLUDGE DEWATERING
PROCESSES
FILTRATION
CARBON ADSORPTION
REVERSE OSMOSIS
EVAPORATION
ONSITE REUSE
STEAM TO ATMOSPHERE
CONDENSATE (AS REQ'D)
EVAPORATION
EMULSION BREAKING
CENTRIFUGATION
AIR FLOTATION
AQUEOUS
ORGANICS
INORGANIC RESIDUES
SOLIDIFICATION
ENGINEERED LANDFILL
NIC RESIDUES
INCINERATION

FIGURE 1

PHYSICAL/CHEMICAL TREATMENT
SCHEMATIC DIAGRAM

- o treating miscellaneous inorganic wastes generated on site,
- o treatment of effluents from the aqueous/organic treatment system, and
- o retreating batches of effluent which fail to meet the treatment objectives.

The capacity of the system can be expanded to treat the total estimated quantity of inorganic waste outlined in Table 2 (p. 12) by operating additional shifts.

This arrangement is desirable and practical in terms of maximizing the performance and flexibility of the inorganic process system for the following reasons

- o The total volume of waste which has been designated for treatment in the inorganic treatment system is sufficiently small to enable batch treatment methods to be adopted for these wastes. This mode of operation will maximize the control and effectiveness of each stage of the treatment process.

- o The maximum anticipated quantity of inorganic waste can be handled by operating additional shifts each day rather than by oversizing the inorganic treatment system.

The inorganic treatment system consists of the following unit processes:

- o Primary treatment
  - phase separation
  - dissolution/slurrying
  - blending

- Secondary treatment
  - oxidation/reduction
  - neutralization/precipitation
  - coagulation/sedimentation
  - sludge dewatering

- Intermediate storage

- Effluent Polishing
  - granular media filtration
  - activated carbon adsorption
  - reverse osmosis

- Final Effluent Storage

- Evaporation

These unit processes are further described in Section 4.3.2 (p. 142).

4.2.2 AQUEOUS ORGANIC TREATMENT SYSTEM

A separate process train has been provided to treat aqueous organic mixtures. This approach offers a number of advantages related to the performance, safety, flexibility, reliability, and cost of the physical/chemical treatment system as follows:

- The performance and reliability of the physical/chemical treatment system is improved by removing immiscible (and dissolved) organics to the extent possible prior to subsequent treatment steps. This approach is consistent with achieving a stagewise reduction in contaminants and will serve to:
  - minimize downstream equipment fouling in the inorganic process system,
  - reduce the potential for cross contamination of inorganic and aqueous organic wastes, and

  - improve the efficiency of subsequent metal precipitation and solids separation steps since the presence of immiscible organics can hinder the settling of precipitated solids.

- Added process flexibility is achieved by having process equipment which is dedicated to the treatment of mixtures of immiscible organics and water.

- Treating aqueous organic wastes with dedicated aqueous organic process train equipment segregated from the remainder of the physical/chemical processing steps avoids specifying explosion proof equipment throughout the physical/ chemical plant.

The aqueous organic treatment system will be designed to treat approximately 9000 t/a of selected aqueous organic wastes in batches based on an 8 hour per day operation, 250 days per year. Additional shifts will be operated as required to treat the total volume of aqueous organic wastes expected when OWMC's Facility reaches its capacity of 150 000 t/a (see Table 2, p. 12). This capacity provides sufficient flexibility for the system to also treat selected on-site generated aqueous organic wastes such as flush and wash waters containing immiscible organics and provides an allowance for treating inorganic wastes which contain immiscible organics. Only those aqueous organic wastes which are demonstrated (by means of on-site laboratory treatability tests) to be amenable to physical/chemical treatment methods will be routed to the physical/chemical process plant for treatment (Refer to Note 1, p. 8). All other aqueous/organic wastes will be incinerated.

The aqueous organic treatment system consists of the following unit processes:

- Primary Treatment
  - phase separation
  - blending

- Secondary Treatment
    - emulsion breaking
    - centrifugation
    - dissolved air flotation
    - activated carbon adsorption

- Intermediate Storage

From intermediate storage, batches of partially treated aqueous/organic wastes will receive additional secondary and/or effluent polishing treatment in the inorganic process system.

These unit processes are further described in Section 4.3.3 (p. 157).

4.2.3 MISCELLANEOUS WASTE TREATMENT SYSTEM

One of the key philosophies which has been adopted for the design of the physical/chemical treatment system is that batch treatment methods be used to the extent possible to maximize the control and effectiveness of each stage of the treatment process. The estimated quantities of inorganic and aqueous/organic wastes are sufficiently low for batch treatment methods to be practical for these wastes. However, this is not likely to be the case with miscellaneous wastes which may require treatment. All surface drainage from the active areas of the landfill and potentially contaminated surface drainage from the landfill along with drainage from the central operating area will be collected and its quality checked before being discharged from the site. Water quality checks will also be carried out on a routine basis on the leachate from the landfill. If necessary, these "miscellaneous wastes" will be treated by physical/chemical methods prior to being reused on site or discharged to atmosphere by evaporation. To ensure that adequate physical/chemical treatment capacity is available to treat potentially large volumes of relatively dilute miscellaneous wastes, these wastes will be treated in a separate, dedicated, continuous flow treatment system located in the physical/chemical treatment building.

This approach has been chosen for the following reasons:

- o Landfill leachates and contaminated surface drainages which require treatment can be treated without adversely affecting the capacity of the physical/chemical plant for batch treating inorganic and aqueous/organic special wastes.

- o The use of batch treatment methods will be preserved for the more concentrated inorganic and aqueous/organic special wastes. By comparison, the miscellaneous waste streams are expected to have low concentrations of contaminants.

- o This approach eliminates the need to oversize the batch treatment system to enable it to treat potentially large volumes of relatively dilute miscellaneous waste.

It should be noted that it will also be possible to treat miscellaneous wastes in the batch treatment system. However, this would only be the case during periods when the volumes involved are low and there is excess capacity in the batch treatment system, or if a particular batch of miscellaneous waste becomes highly contaminated.

The quantity of surface drainage and landfill leachate requiring treatment will depend upon the actual characteristics of both leachate and potentially contaminated surface water collected at the Facility. The quantity of leachate is also time dependent, since it will increase with the size of the developed area of the engineered landfill.

The determining factor in establishing the capacity of the miscellaneous waste treatment system is the requirement to process the contents of the potentially contaminated surface water pond in a reasonable period of time. A period of about one week has been established for this purpose, and this results in a nominal system design capacity of 50 t/h based on continuous 24 hour per day operation. At this capacity the total contents of one of the surface drainage ponds in the central operating area can be treated in 10 days and the average monthly rainfall can be treated in 5 days.

The miscellaneous waste treatment system will consist of the following physical/chemical treatment processes:

- o Primary/secondary treatment
  - equalization
  - neutralization/precipitation
  - flocculation/sedimentation
  - sludge dewatering

- o Effluent polishing
  - granular media filtration
  - activated carbon adsorption
  - reverse osmosis

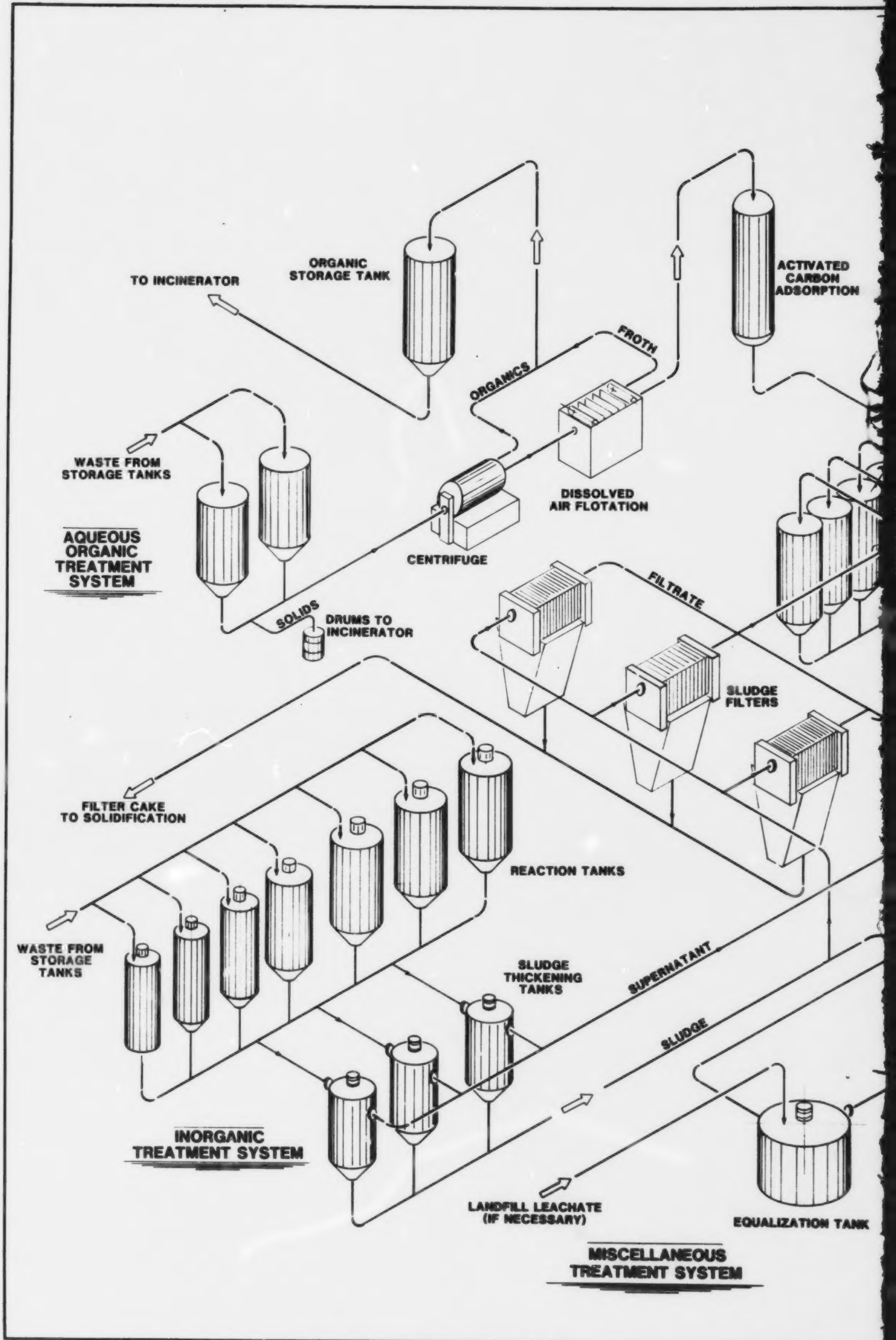
- o Final effluent storage
- o Evaporation

The design of these processes is further described in Section 4.3.4 (p. 160).

4.3 SYSTEM OPTIMIZATION

4.3.1 EQUIPMENT SELECTION AND SIZING

Figure 2 provides a pictorial illustration of the main components of each treatment system in the physical/chemical plant. Figure 3 identifies the location of the physical/chemical plant within OWMC's Facility. Figures 4 to 8 show the configuration of equipment within the physical/chemical tank storage area and the physical/chemical plant. The following paragraphs, which should be read in conjunction with these Figures, describe the rationale behind the design of each of these components with regard to:


ORGANIC STORAGE TANK
TO INCINERATOR
ACTIVATED CARBON ADSORPTION
FROTH
ORGANICS
WASTE FROM STORAGE TANKS
DISSOLVED AIR FLOTATION
AQUEOUS ORGANIC TREATMENT SYSTEM
CENTRIFUGE
FILTRATE
SOLIDS
DRUMS TO INCINERATOR
SLUDGE FILTERS
FILTER CAKE TO SOLIDIFICATION
REACTION TANKS
WASTE FROM STORAGE TANKS
SLUDGE THICKENING TANKS
SUPERNATANT
SLUDGE
INORGANIC TREATMENT SYSTEM
LANDFILL LEACHATE (IF NECESSARY)
EQUALIZATION TANK
MISCELLANEOUS TREATMENT SYSTEM

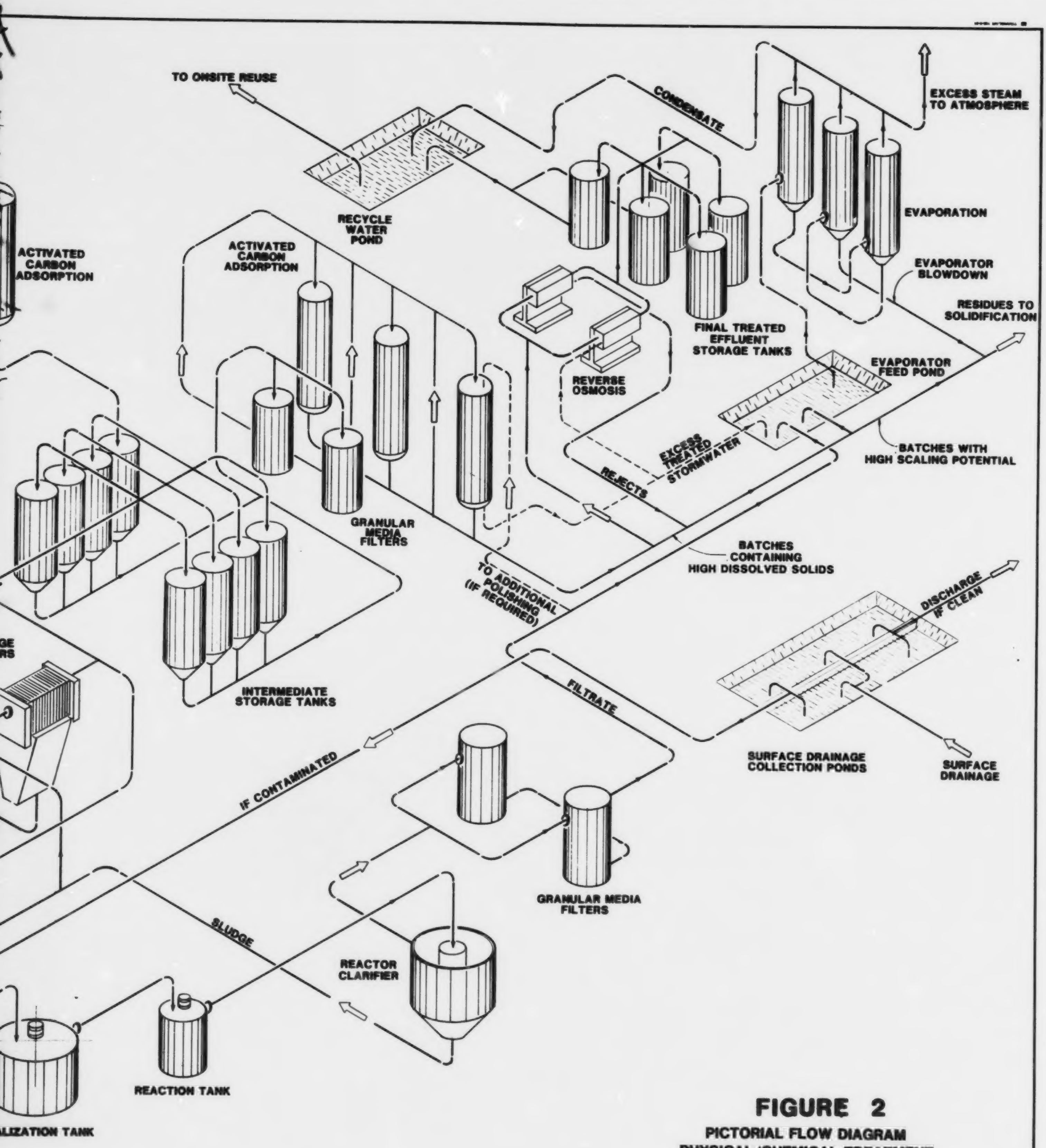
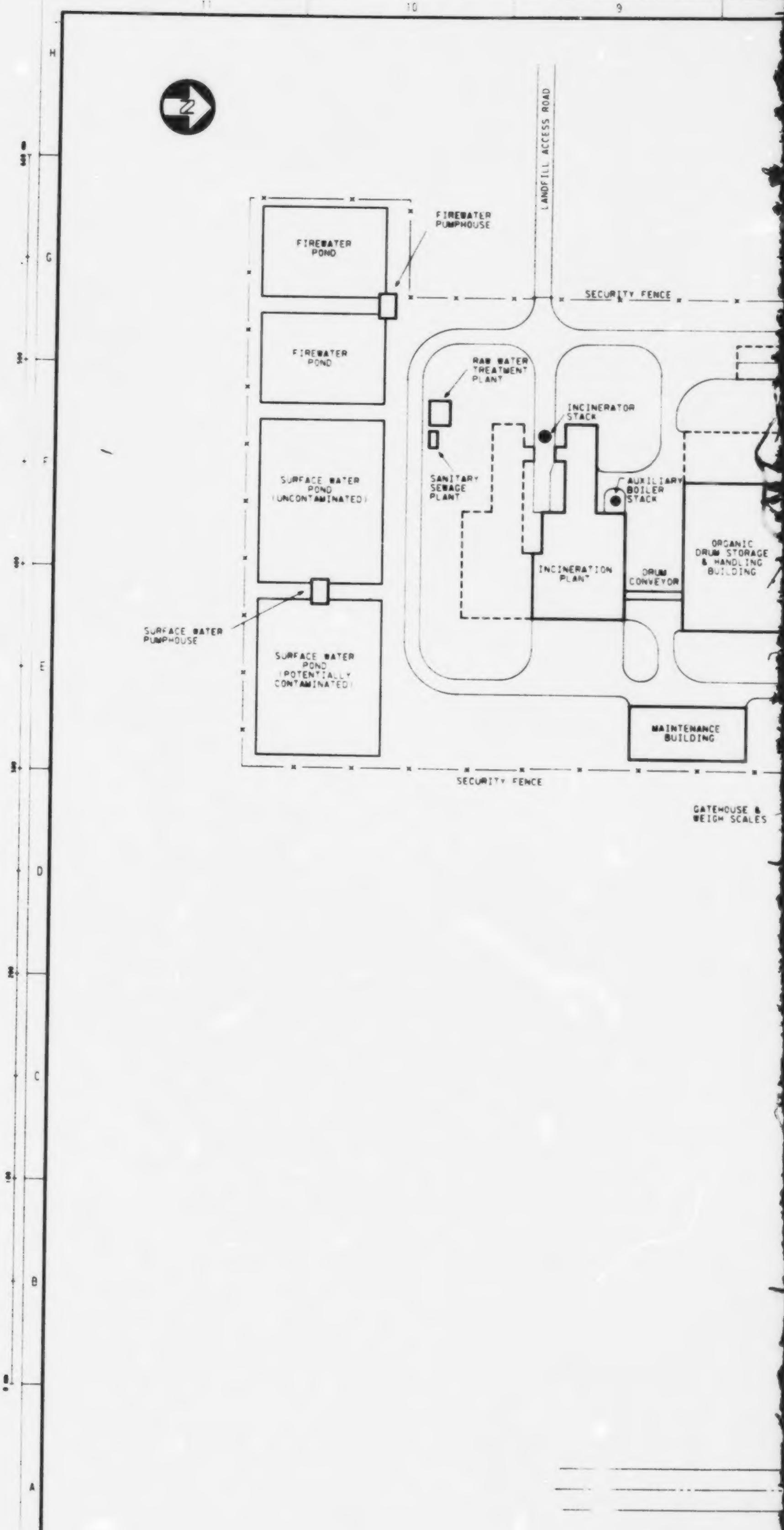

TO ONSITE REUSE
CONDENSATE
EXCESS STEAM TO ATMOSPHERE
RECYCLE WATER POND
ACTIVATED CARBON ADSORPTION
ACTIVATED CARBON ADSORPTION
EVAPORATION
EVAPORATOR BLOWDOWN
RESIDUES TO SOLIDIFICATION
FINAL TREATED EFFLUENT STORAGE TANKS
REVERSE OSMOSIS
EVAPORATOR FEED POND
EXCESS TREATED STORMWATER
REJECTS
BATCHES WITH HIGH SCALING POTENTIAL
GRANULAR MEDIA FILTERS
BATCHES CONTAINING HIGH DISSOLVED SOLIDS
TO ADDITIONAL POLISHING (IF REQUIRED)
DISCHARGE IF CLEAN
GE
RS
INTERMEDIATE STORAGE TANKS
FILTRATE
SURFACE DRAINAGE COLLECTION PONDS
SURFACE DRAINAGE
IF CONTAMINATED
GRANULAR MEDIA FILTERS
SLUDGE
REACTOR CLARIFIER
REACTION TANK
ALIZATION TANK

FIGURE 2

PICTORIAL FLOW DIAGRAM
PHYSICAL/CHEMICAL TREATMENT



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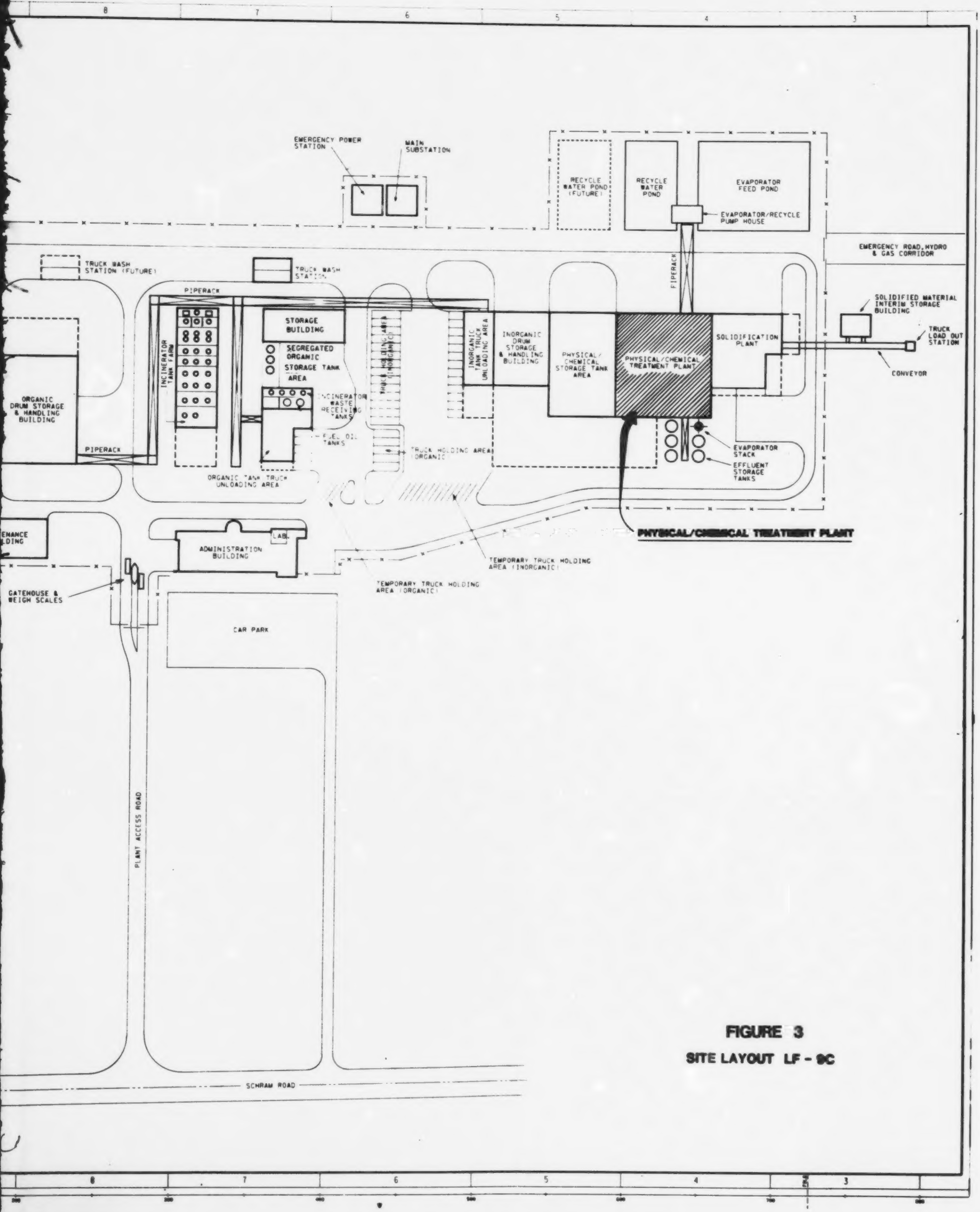
N
LANDFILL ACCESS ROAD
FIREWATER POND
FIREWATER PUMPHOUSE
SECURITY FENCE
FIREWATER POND
RAW WATER TREATMENT PLANT
INCINERATOR STACK
SANITARY SEWAGE PLANT
AUXILIARY BOILER STACK
SURFACE WATER POND (UNCONTAMINATED)
INCINERATION PLANT
DRUM CONVEYOR
ORGANIC DRUM STORAGE & HANDLING BUILDING
SURFACE WATER PUMPHOUSE
SURFACE WATER POND (POTENTIALLY CONTAMINATED)
MAINTENANCE BUILDING
SECURITY FENCE
GATEHOUSE & WEIGH SCALES


8
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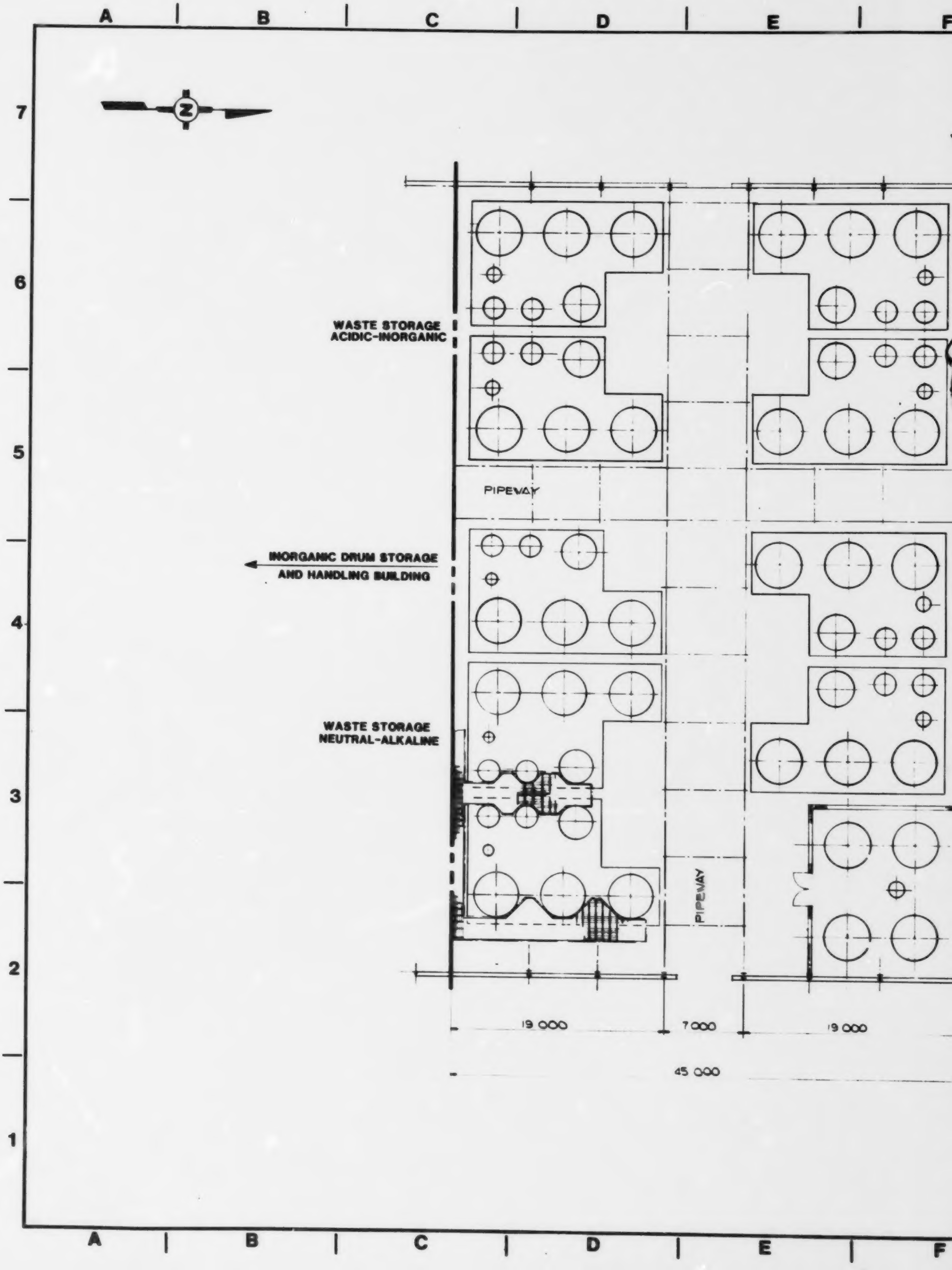
3
EMERGENCY POWER STATION
MAIN SUBSTATION
RECYCLE WATER POND (FUTURE)
RECYCLE WATER POND
EVAPORATOR FEED POND
EVAPORATOR/RECYCLE PUMP HOUSE
EMERGENCY ROAD, HYDRO & GAS CORRIDOR
TRUCK WASH STATION (FUTURE)
TRUCK WASH STATION
PIPERACK
PIPERACK
SOLIDIFIED MATERIAL INTERIM STORAGE BUILDING
TRUCK LOAD OUT STATION
CONVEYOR
INCINERATOR TANK FARM
STORAGE BUILDING
SEGREGATED ORGANIC STORAGE TANK AREA
INCINERATOR WASTE RECEIVING TANKS
FUEL OIL TANKS
TRUCK HOLDING AREA (INORGANIC)
INORGANIC TANK TRUCK UNLOADING AREA
INORGANIC DRUM STORAGE & HANDLING BUILDING
PHYSICAL/CHEMICAL STORAGE TANK AREA
PHYSICAL/CHEMICAL TREATMENT PLANT
SOLIDIFICATION PLANT
EVAPORATOR STACK
EFFLUENT STORAGE TANKS
ORGANIC DRUM STORAGE & HANDLING BUILDING
PIPERACK
ORGANIC TANK TRUCK UNLOADING AREA
TRUCK HOLDING AREA (ORGANIC)
PHYSICAL/CHEMICAL TREATMENT PLANT
ENANCE
LDING
ADMINISTRATION BUILDING
LAB.
TEMPORARY TRUCK HOLDING AREA (INORGANIC)
TEMPORARY TRUCK HOLDING AREA (ORGANIC)
GATEHOUSE & WEIGH SCALES
CAR PARK
PLANT ACCESS ROAD
SCHRAM ROAD

FIGURE 3

SITE LAYOUT LF - 9C


A
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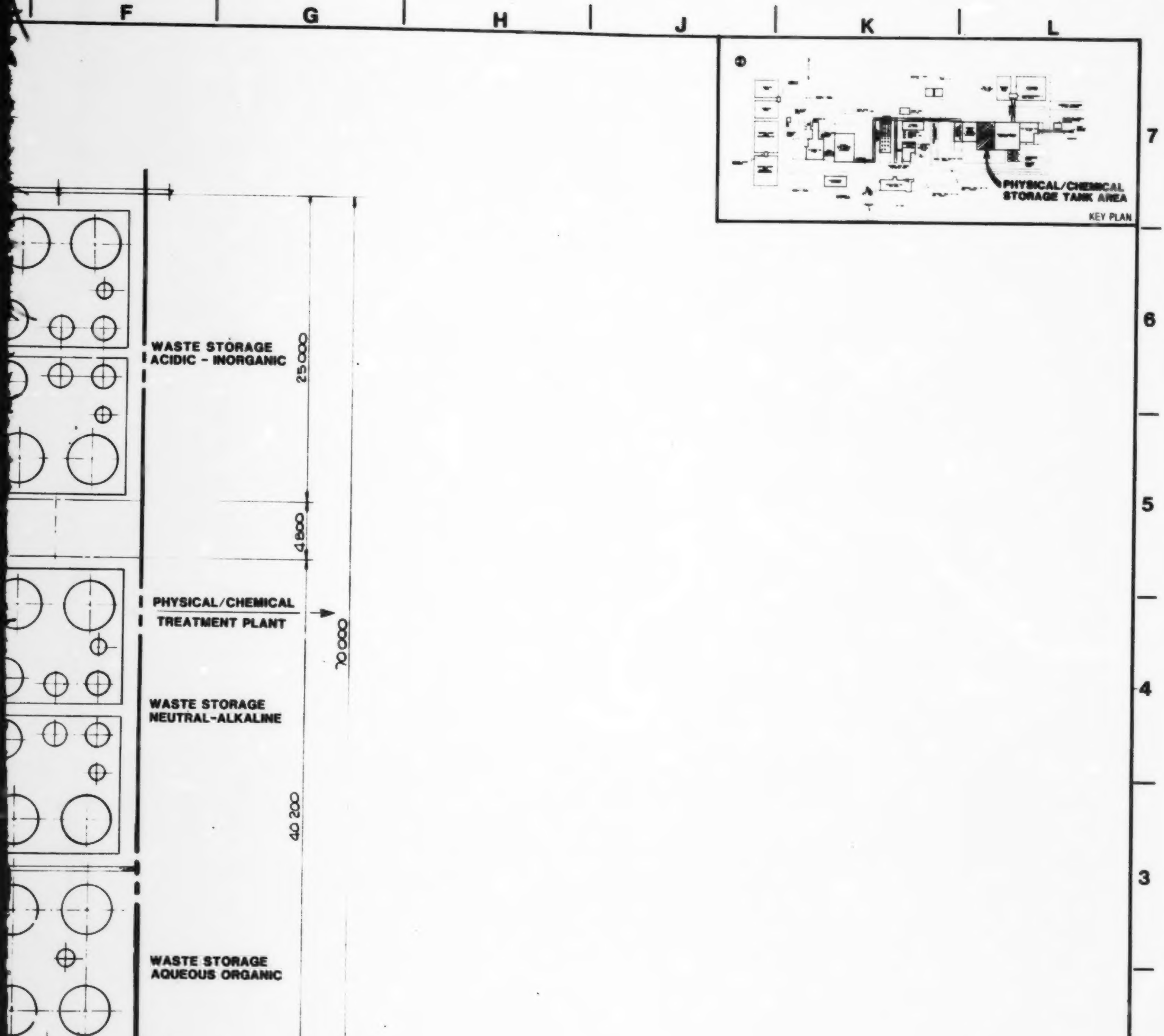
N
WASTE STORAGE
ACIDIC-INORGANIC
PIPEWAY
INORGANIC DRUM STORAGE
AND HANDLING BUILDING
WASTE STORAGE
NEUTRAL-ALKALINE
PIPEWAY
19 000
7000
19 000
45 000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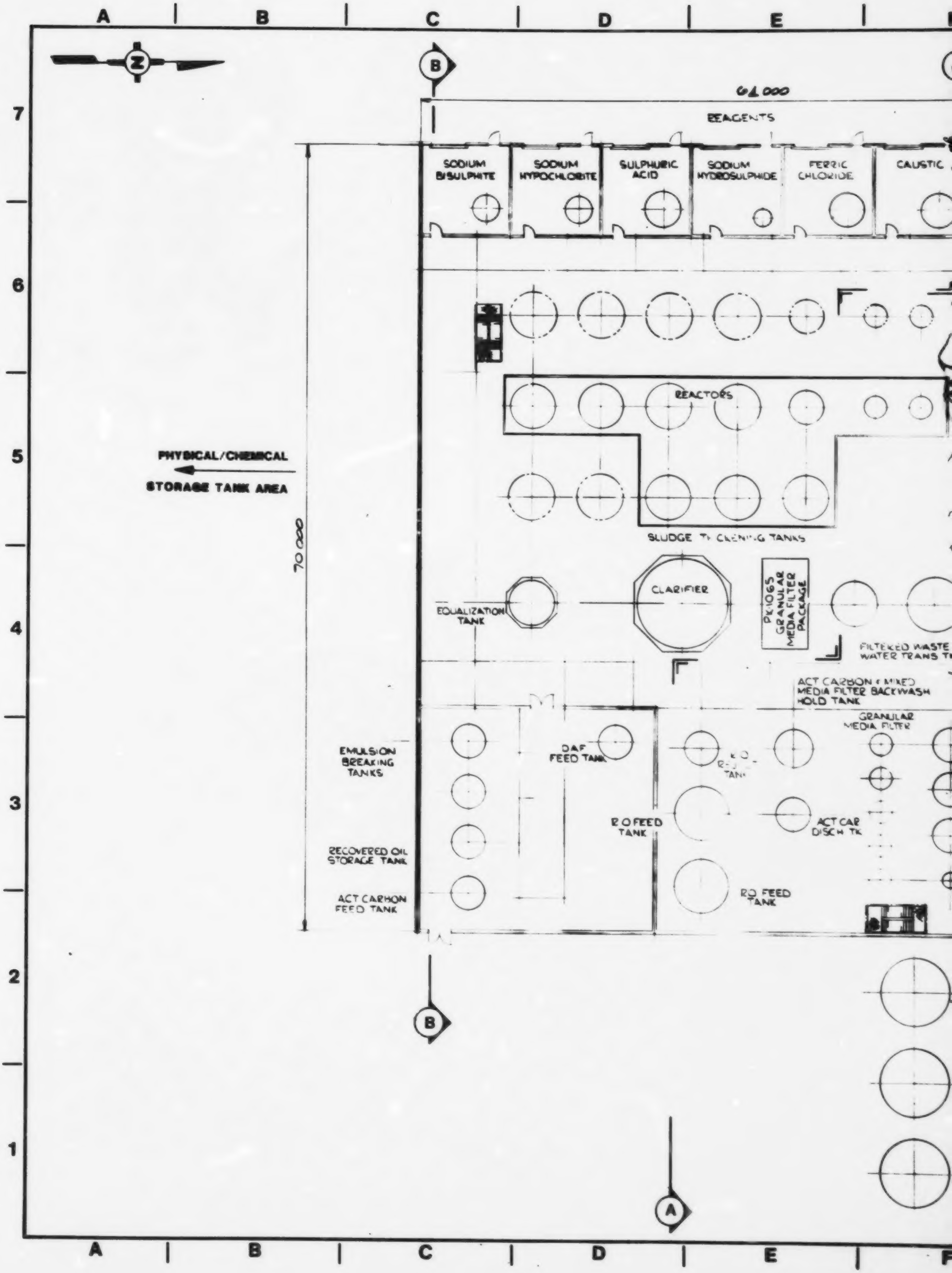
PHYSICAL/CHEMICAL STORAGE TANK AREA
KEY PLAN
WASTE STORAGE ACIDIC - INORGANIC
25 000
4800
PHYSICAL/CHEMICAL TREATMENT PLANT
70 000
WASTE STORAGE NEUTRAL-ALKALINE
40 200
WASTE STORAGE AQUEOUS ORGANIC
000

FIGURE 4

PHYSICAL/CHEMICAL STORAGE TANK AREA
CONCEPTUAL EQUIPMENT LAYOUT
PLAN


A
B
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B
61 000
REAGENTS
SODIUM BISULPHITE
SODIUM HYPOCHLORITE
SULPHURIC ACID
SODIUM HYDROSULPHIDE
FERRIC CHLORIDE
CAUSTIC
REACTORS
PHYSICAL/CHEMICAL
STORAGE TANK AREA
70 000
SLUDGE THICKENING TANKS
EQUALIZATION TANK
CLARIFIER
PK-1065 GRANULAR MEDIA FILTER PACKAGE
FILTERED WASTE WATER TRANS TK
ACT CARBON & MIXED MEDIA FILTER BACKWASH HOLD TANK
GRANULAR MEDIA FILTER
EMULSION BREAKING TANKS
DAF FEED TANK
RO REJECT TANK
RO FEED TANK
ACT CAR DISCH TK
RECOVERED OIL STORAGE TANK
ACT CARBON FEED TANK
RO FEED TANK
B
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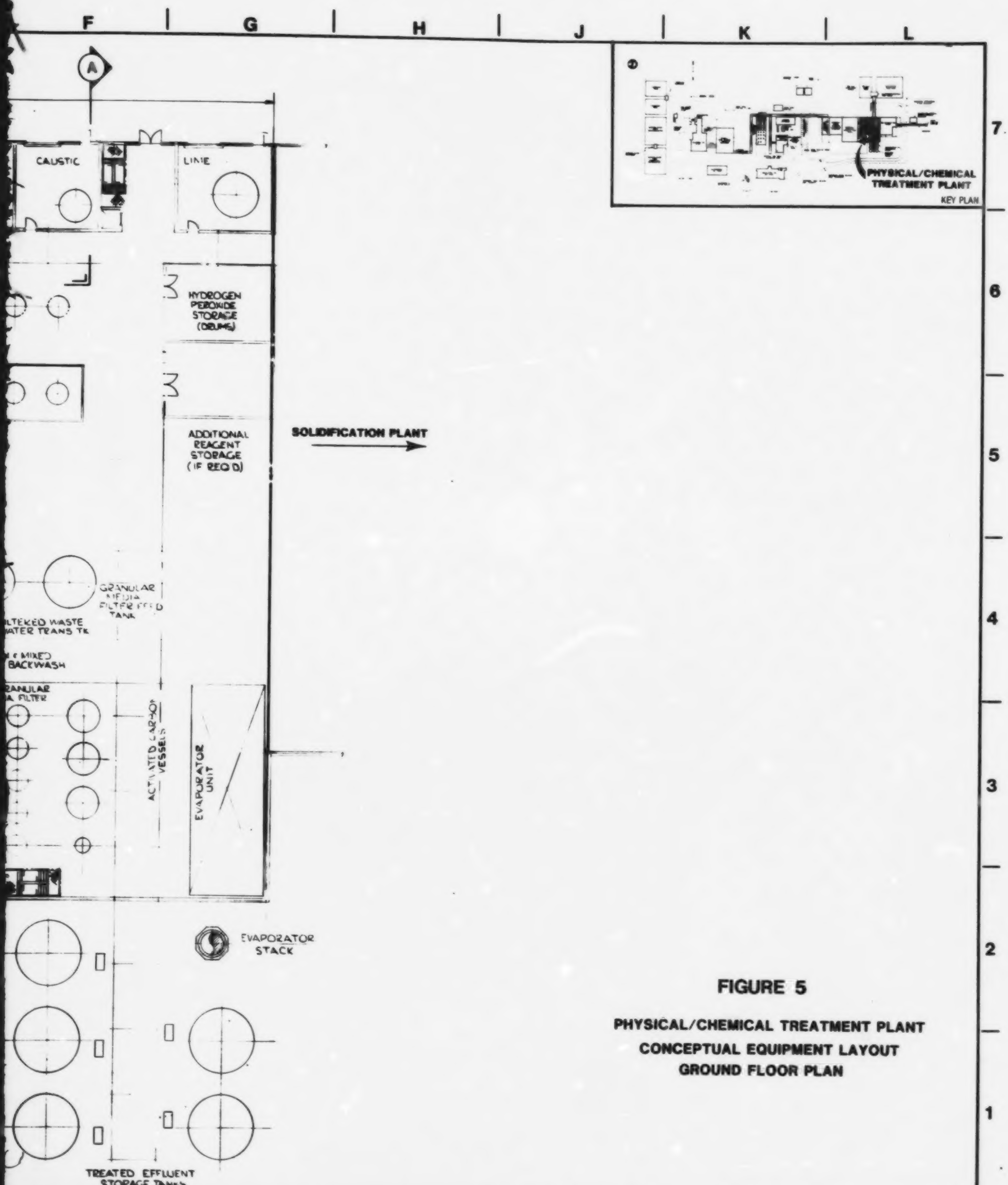
A
B
C
D
E
F


F
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L
A
CAUSTIC
LIME
HYDROGEN
PEROXIDE
STORAGE
(DRUMS)
ADDITIONAL
REAGENT
STORAGE
(IF REQ'D)
SOLIDIFICATION PLANT
GRANULAR
MEDIA
FILTER FEED
TANK
LTERED WASTE
ATER TRANS TK
MIXED
BACKWASH
RANULAR
A FILTER
ACTIVATED CARBON
VESSELS
EVAPORATOR
UNIT
EVAPORATOR
STACK
TREATED EFFLUENT
STORAGE TANKS
PHYSICAL/CHEMICAL
TREATMENT PLANT
KEY PLAN
7
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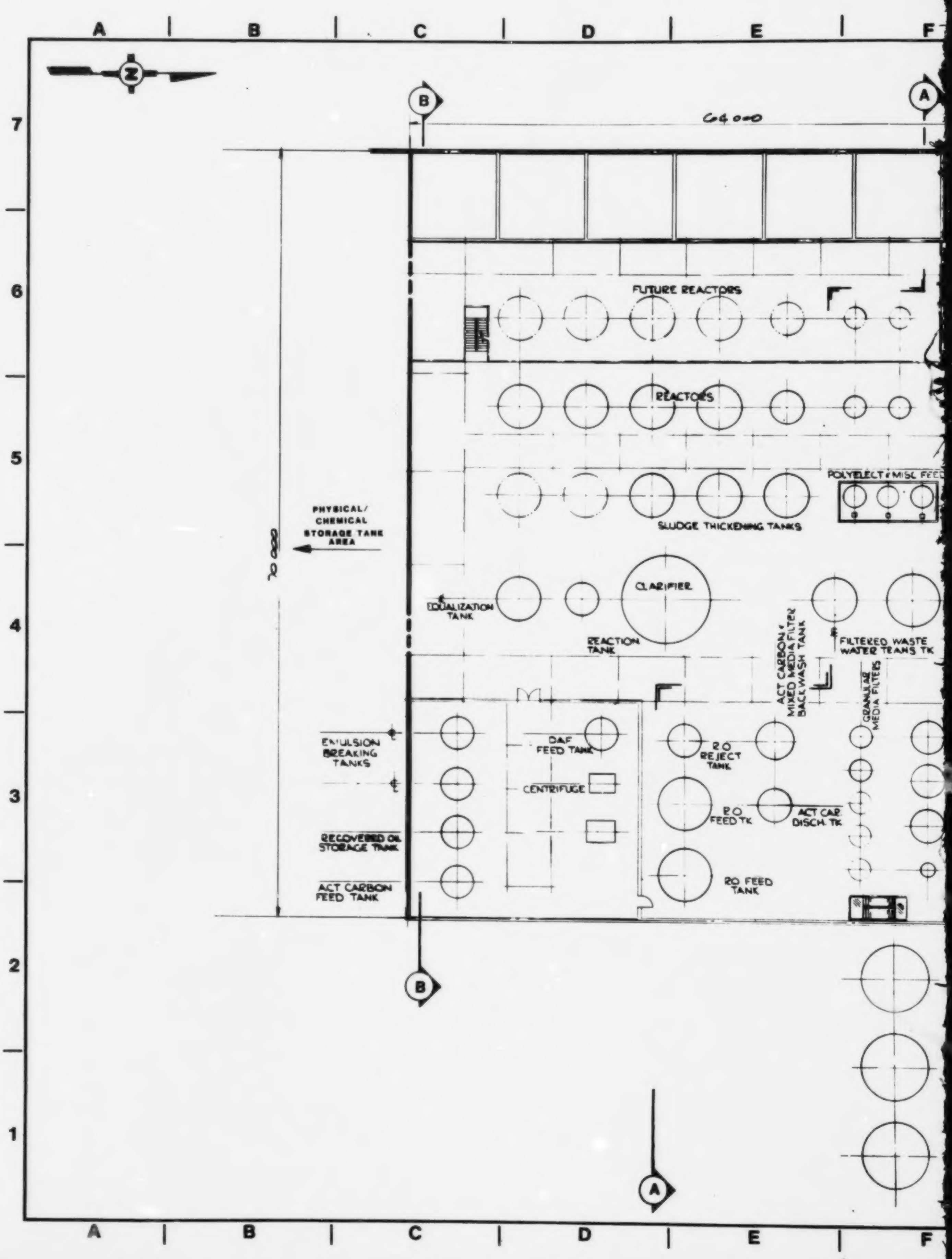
1

FIGURE 5

PHYSICAL/CHEMICAL TREATMENT PLANT
CONCEPTUAL EQUIPMENT LAYOUT
GROUND FLOOR PLAN


A
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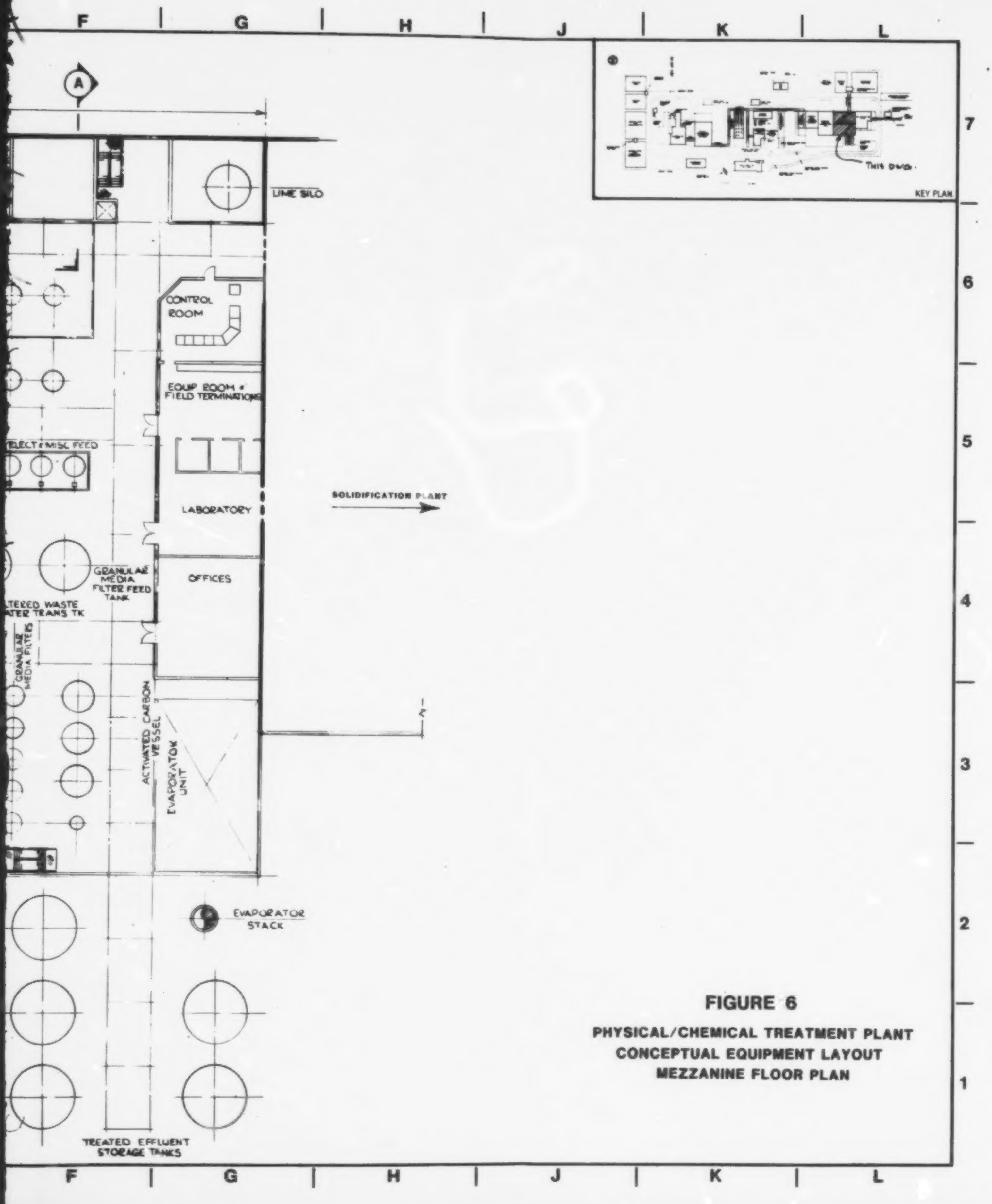
4
3
2
1
B
A
640-0
200-0
FUTURE REACTORS
REACTORS
POLYELECT & MISC FEED
SLUDGE THICKENING TANKS
PHYSICAL/
CHEMICAL
STORAGE TANK
AREA
CLARIFIER
EQUALIZATION
TANK
REACTION
TANK
ACT CARBON &
MIXED MEDIA FILTER
BACKWASH TANK
FILTERED WASTE
WATER TRANS TK
GRANULAR
MEDIA FILTERS
EMULSION
BREAKING
TANKS
DAF
FEED TANK
CENTRIFUGE
RO
REJECT
TANK
RO
FEED TK
ACT CAR.
DISCH. TK
RECOVERED OIL
STORAGE TANK
ACT CARBON
FEED TANK
RO FEED
TANK


F
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K
L
A
LIME SILO
CONTROL ROOM
EQUIP ROOM & FIELD TERMINATIONS
LECT & MISC FEED
LABORATORY
SOLIDIFICATION PLANT
OFFICES
GRANULAR MEDIA FILTER FEED TANK
LTERED WASTE
ATER TRANS TK
GRANULAR MEDIA FILTERS
ACTIVATED CARBON VESSEL
EVAPORATOR UNIT
EVAPORATOR STACK
TREATED EFFLUENT STORAGE TANKS
THIS DWG.
KEY PLAN
7
6
5
4
3
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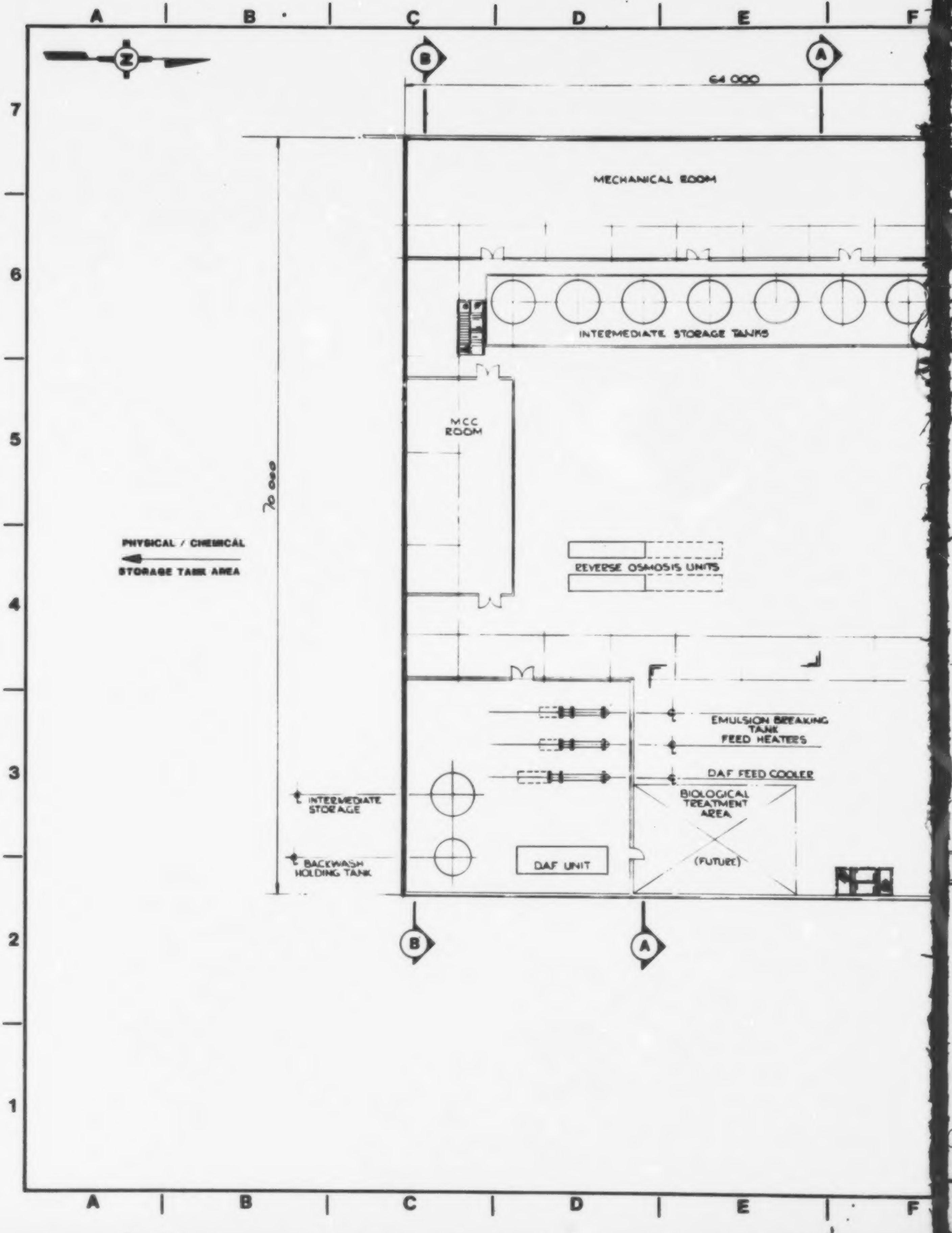
1

FIGURE 6

PHYSICAL/CHEMICAL TREATMENT PLANT
CONCEPTUAL EQUIPMENT LAYOUT
MEZZANINE FLOOR PLAN


A
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7
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2
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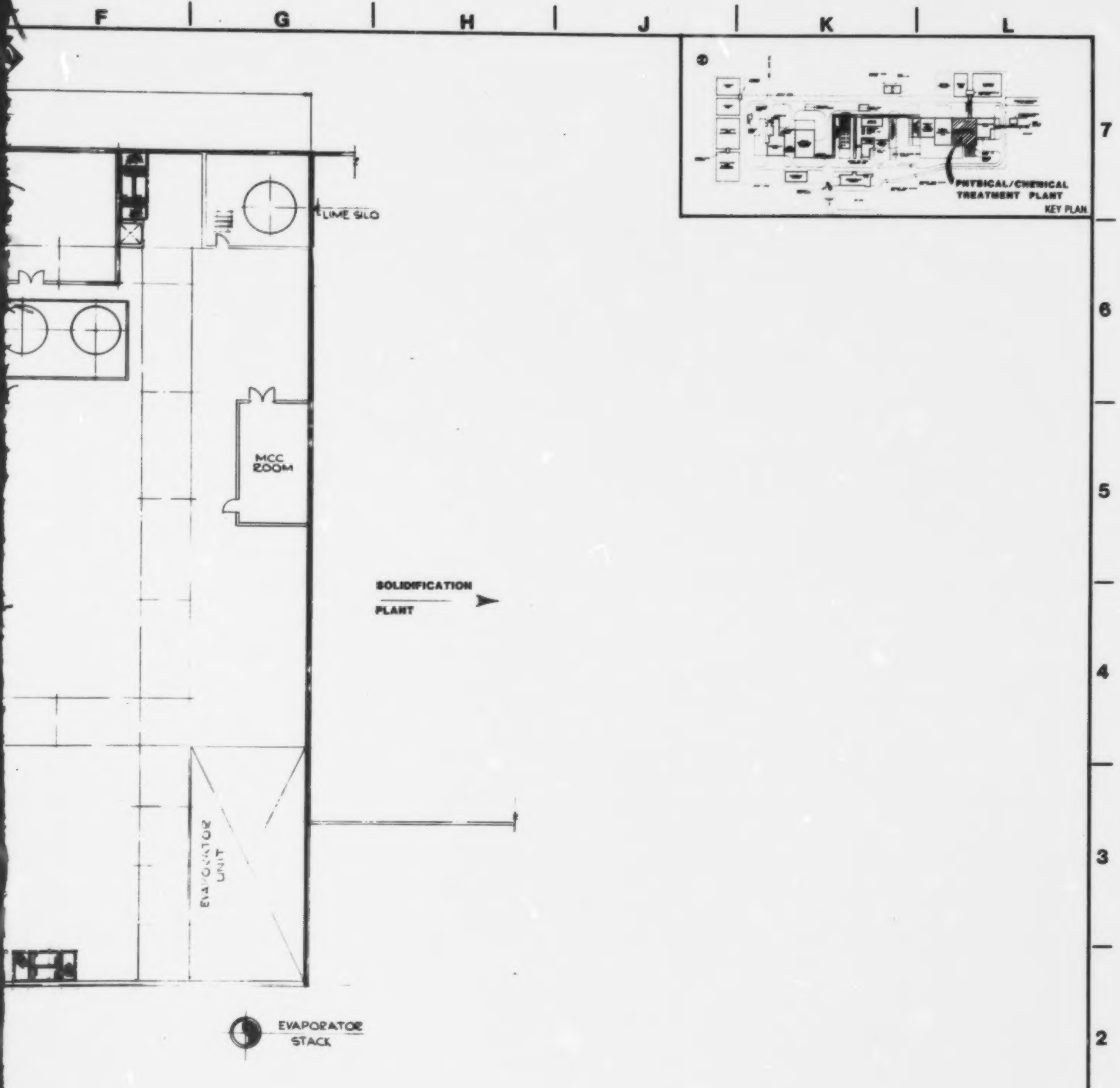
Z
B
A
64 000
70 000
MECHANICAL ROOM
INTERMEDIATE STORAGE TANKS
MCC ROOM
PHYSICAL / CHEMICAL
STORAGE TANK AREA
REVERSE OSMOSIS UNITS
EMULSION BREAKING TANK FEED HEATERS
DAF FEED COOLER
BIOLOGICAL TREATMENT AREA
(FUTURE)
INTERMEDIATE STORAGE
BACKWASH HOLDING TANK
DAF UNIT


F
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J
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L
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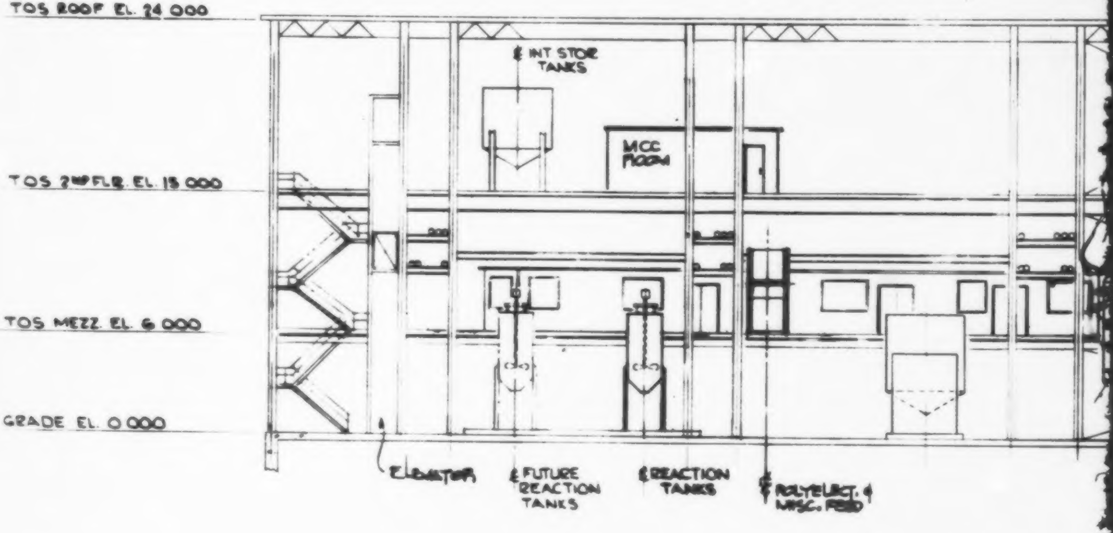
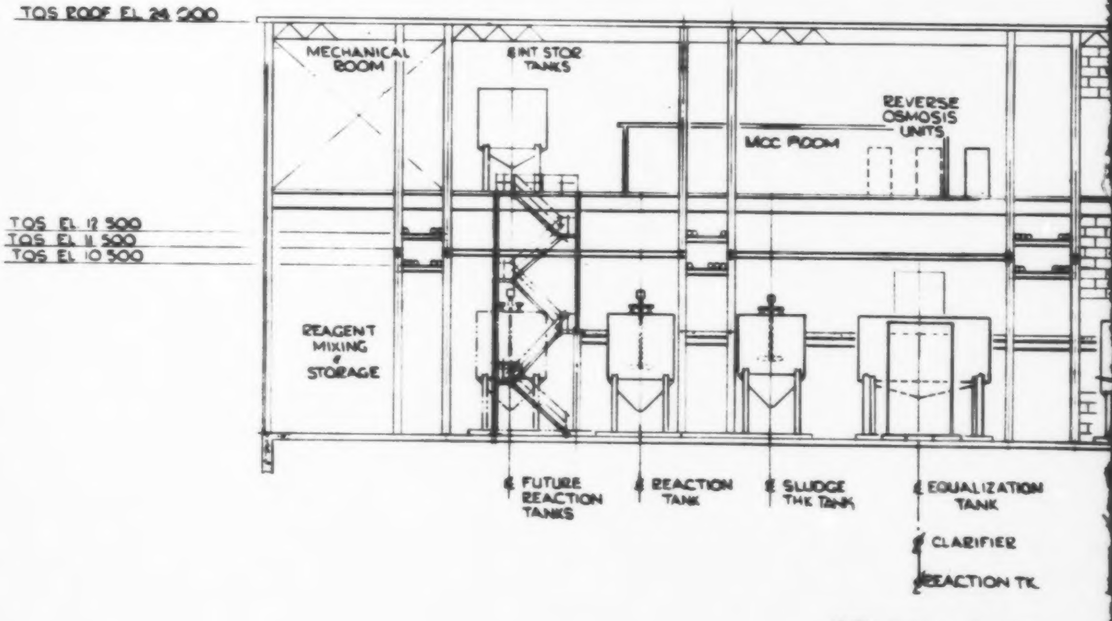
1
PHYSICAL/CHEMICAL TREATMENT PLANT
KEY PLAN
LIME SILO
MCC ROOM
SOLIDIFICATION PLANT
EVAPORATOR UNIT
EVAPORATOR STACK

FIGURE 7

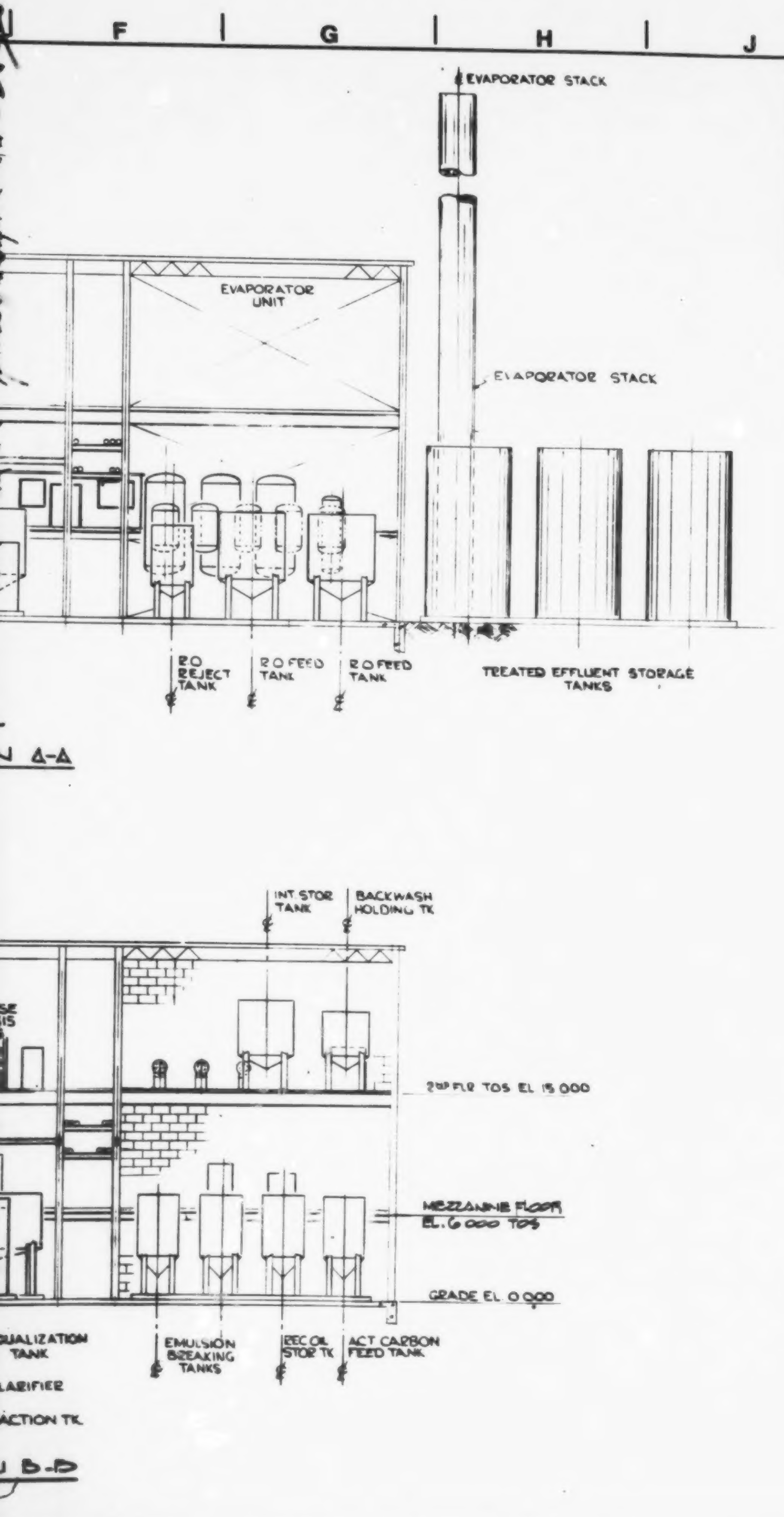
PHYSICAL/CHEMICAL TREATMENT PLANT
CONCEPTUAL EQUIPMENT LAYOUT
PLAN-SECOND FLOOR


TOS ROOF EL. 24 000
TOS 2ND FLR. EL. 15 000
TOS MEZZ. EL. 6 000
GRADE EL. 0 000
℄ INT STOR TANKS
MCC ROOM
ELEVATOR
℄ FUTURE REACTION TANKS
℄ REACTION TANKS
℄ POLYELECT. & MISC. FEED

SECTION A-A


TOS ROOF EL 24 000
TOS EL 12 500
TOS EL 11 500
TOS EL 10 500
MECHANICAL ROOM
℄ INT STOR TANKS
MCC ROOM
REVERSE OSMOSIS UNITS
REAGENT MIXING & STORAGE
℄ FUTURE REACTION TANKS
℄ REACTION TANK
℄ SLUDGE THK TANK
℄ EQUALIZATION TANK
℄ CLARIFIER
℄ REACTION TK.

SECTION B-B


F
G
H
J
EVAPORATOR STACK
EVAPORATOR UNIT
EVAPORATOR STACK
RO REJECT TANK
RO FEED TANK
RO FEED TANK
TREATED EFFLUENT STORAGE TANKS
N A-A
INT. STOR TANK
BACKWASH HOLDING TK
SE
IS
2ND FLR TOS EL 15.000
MEZZANINE FLOOR EL. 6.000 TOS
GRADE EL 0.000
SUALIZATION TANK
EMULSION BREAKING TANKS
REC OIL STOR TK
ACT CARBON FEED TANK
LARIFIER
ACTION TK
N B-B
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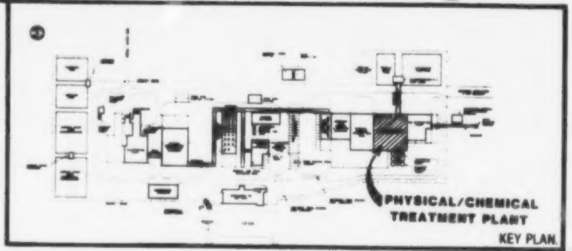
PHYSICAL/CHEMICAL TREATMENT PLANT
KEY PLAN.

FIGURE 8

PHYSICAL/CHEMICAL TREATMENT PLANT
CONCEPTUAL EQUIPMENT LAYOUT
SECTIONS

- equipment selection and sizing,
- the manner in which each component has been integrated into the overall physical/chemical treatment facility, and
- the measures taken to maximize system performance, safety, flexibility and reliability in a cost effective manner.

Waste Storage (inorganic and aqueous organic)

Storage tanks for inorganic and aqueous organic wastes will be located in a separate building enclosure adjoining the physical/chemical building (Figure 4 p. 134). The aqueous organic storage tanks will be separated from the inorganic storage tanks by a solid wall for safety and fire protection purposes. Miscellaneous wastes will be stored separately in ponds located on the plant site and in the landfill area. Information concerning the design of the miscellaneous waste storage facilities is presented in separate process area reports dealing with the Landfill (Monenco Limited[8]) and General Facilities (Monenco Limited[9]).

The inorganic and aqueous organic waste storage tanks are designed to fulfill several primary treatment functions in addition to storing untreated wastes prior to treatment. These include:

- blending compatible wastes to enhance treatability,
- maintaining solids and immiscible liquids in suspension (where necessary) to facilitate sampling and transfer, and
- allowing gravity separation to take place (where necessary) to improve the effectiveness of subsequent treatment steps.

To provide the necessary operational flexibility, all of the waste storage tanks will be equipped with agitators to enable wastes to be blended and solids kept in suspension as required. Each storage tank will also be equipped with a conical bottom to enhance the efficiency of phase separation where required.

More efficient use of available waste storage and treatment capacity is achieved by having the capability to blend batches of waste from different sources prior to treatment provided that the treatability of the resulting mixture is not adversely affected. Treatment of one waste with another will be carried out in the reaction tanks.

Primary phase separation (where necessary and practical) will normally be allowed to take place in the waste storage tanks prior to treatment. This approach eliminates the need to provide additional items of process equipment specifically for this purpose. The main objective of this step is to allow flotable oils and/or settlable solids to separate from the aqueous phase by gravity under quiescent conditions before each of the recovered phases undergo further physical chemical treatment.

A total inorganic waste storage capacity of 1600 m^3 will be provided for untreated wastes as follows:

- 31 tanks each 40 m^3 capacity
- 9 tanks each 20 m^3 capacity
- 18 tanks each 10 m^3 capacity

This will provide approximately 8 days storage of special wastes based on an 8 hour per day operation or 4 days storage of liquid waste based on the initial design capacity of the plant (i.e. 120 000 t/a). Storage for non-pumpable inorganic wastes will be provided in the solidification plant.

The total liquid waste storage capacity has been selected based on providing a minimum of:

- one day storage for incoming waste,
- one day inventory, ready for treatment,
- one day inventory for additional treatability testing purposes, and
- additional storage for special wastes requiring longer storage for treatability tests and to allow for some partially full tanks.

The number and size of the inorganic waste storage tanks has been selected on the basis of providing a larger number of smaller tanks rather than a small number of large tanks for the following reasons:

- To maximize the extent to which wastes of different chemical compositions can be kept segregated in order to maximize the effectiveness of the required treatment processes.

- To provide storage tank capacities which match the range of bulk tank truck sizes (10 t to 40 t) which are expected to deliver wastes to OWMC's Facility.

Based on the approximate quantities of each waste type given in OWMC's waste profile information, the waste storage tanks will be segregated according to the major categories of waste being stored as follows:

- 24 tanks for acidic wastes (4 groups of 6 tanks)
- 30 tanks for neutral and alkaline wastes (5 groups of 6 tanks)
- 4 tanks for mixed aqueous/organic wastes (1 group of 4 tanks)

This arrangement, which provides groups of storage tanks within each major category, will also enable wastes to be further segregated within each major category. For example, one or more groups of neutral and alkaline storage tanks can be designated for storing cyanide containing waste. Similarly strong alkalis can be segregated from weak alkalis and strong acids from weak acids. To provide adequate processing flexibility, each group of tanks, with the exception of the four aqueous organic storage tanks which are all 40 m^3 capacity, will consist of:

- 3 - 40 m^3 capacity tanks,
- 1 - 20 m^3 capacity tank, and
- 2 - 10 m^3 capacity tanks.

Separate header pipes will also be provided for transferring acidic, neutral and alkaline, and aqueous organic wastes from storage into the physical/chemical process plant. This arrangement is designed to:

- minimize the risk of cross contamination and mixing of incompatible wastes,

- enable compatible wastes from two storage tanks to be combined for treatment in a single reaction tank,

- maximize the operational flexibility of the system by enabling more than one reactor to be filled simultaneously, and

- minimize the complexity and cost of piping systems.

The inorganic waste storage tanks will be located inside a heated building adjacent to the physical/chemical plant to eliminate the need to insulate the storage tanks and associated piping and maximize the accessibility of the storage tanks, transfer pumps, piping and instrumentation for ease of maintenance and sample collection.

All inorganic and aqueous/organic waste storage tanks will be closed and vented. Vented air will be passed through a ventilation air scrubbing system before being discharged to the atmosphere. These measures have been included for reasons of occupational health and environmental protection so that:

- potentially noxious vapours and gases are not released inside the building enclosure which houses the waste storage tanks and

- vented air is adequately treated before being released to the atmosphere.

4.3.2 Inorganic Waste Treatment System

Primary Treatment Processes

Phase Separation. Primary phase separation (where required) will be carried out in the waste storage tanks as previously explained on p. 139. The need for primary phase separation will be determined in advance based on laboratory treatability studies.

Dissolution and/or Slurrying. Dissolution and/or slurrying of non-pumpable inorganic solids will only be carried out on solid wastes which require physical/chemical treatment prior to solidification (eg. cyanide containing sludges).

Non-pumpable inorganic waste residues which do not require physical/ chemical treatment will be routed directly to the solidification plant (located adjacent to the physical/chemical treatment plant).

Bulk inorganic solids which require physical/chemical treatment will be dissolved or slurried in one of the bulk inorganic waste unloading basins prior to being pumped into the appropriate inorganic waste storage tanks. Inorganic solids which require crushing or grinding prior to dissolution/slurrying will be processed through the size reduction equipment located in the solidification plant prior to being slurried and sent to the physical/chemical plant for treatment. Thus, all crushing and grinding will be carried out in the solidification plant.

Non-pumpable inorganics which arrive in drums will be dissolved or slurried in the bulk waste unloading basins which are accessible from the drum unloading area. Wastes unloaded from drums will then be pumped into the appropriate waste storage tank for temporary storage or transferred immediately into one of the reaction tanks.

Blending. Blending of inorganic wastes will take place in the waste storage tanks. Laboratory treatability test information will be used as a basis for determining whether two or more wastes can be blended safely without adversely affecting their treatability. Reaction of compatible wastes will be carried out in the reaction tanks in all cases which involve using one waste to treat another such as when an alkaline waste is used to neutralize a compatible acidic waste. This approach will ensure that key process variables such as temperature rise, pH and oxidation/reduction potential (ORP) are properly monitored and controlled.

Secondary Treatment Processes

Chemical Oxidation and Reduction. Four reaction tanks can be used for chemical oxidation and reduction reactions. These reactors will range in size from 10 m^3 to 40 m^3 capacity as follows:

- o 2 - 10 m^3
- o 1 - 20 m^3
- o 1 - 40 m^3

All four oxidation/reduction reactors will be functionally interchangeable for maximum operational flexibility. However, for safety reasons, it is likely that one or more reactors will be designated primarily for oxidation reactions involving contaminants such as cyanides, sulphides, ammonia, arsenic, phenol, organo-metallic complexes and other organics, whereas one or more of the remaining reactors will be designated primarily for reduction reactions involving, for example, reduction of hexavalent chromium. This approach will permit the plant operators to become accustomed to carrying out certain types of reactions and their associated safety procedures in a particular reactor thereby reducing the risk of operational error.

In addition to oxidation/reduction reactions, the four reactors will also be capable of carrying out neutralization/precipitation, coagulation and solids settling steps.

One 10 m^3 reactor and the 20 m^3 reactor will be equipped with cooling jackets to enable the heat liberated by the neutralization of strong acids and alkalis to be removed during the reaction sequence and thus avoid excessive increases in fluid temperature.

All of the reaction tanks will be vertical, cylindrical configurations in order to minimize the number of agitators required to achieve effective agitation during the reaction sequence and to minimize the floor space requirements within the physical/chemical building. In addition, all reaction tanks will be equipped with conical bottoms to enhance the efficiency of phase separation where required and to facilitate the discharge of the entire contents of each tank at the completion of the reaction sequence.

The choice of four oxidation/reduction tanks has been based on providing optimum operational flexibility and reliability as follows:

- Oxidation/reduction reactions which proceed optimally at different pH's (eg. cyanide at alkaline pH and chromium at acidic pH) can be carried out simultaneously on separate batches of waste.

- Multiple reaction tanks will alleviate potential bottlenecks which could result from the excessively long retention times sometimes required to oxidize complexed cyanides and/or organo-metallic complexes.

- All of the oxidation/reduction reactors will also be capable of functioning as precipitation/coagulation/solids separation vessels.

- The transfer of wastes from storage to the reaction tanks is simplified because storage and reaction tank sizes are compatible. The entire contents of a particular storage tank can be transferred to the appropriate sized reaction tank. Level controls in each of the reactors will provide additional protection against overfilling.

- Process equipment utilization will be efficient, particularly for treating smaller batches of waste.

- The smaller 10 and 20 m^3 reaction tanks will enable smaller batches of waste to be kept segregated for optimum treatment. The larger 40 m^3 reactors will enable two or more smaller batches to be combined in cases where laboratory treatability tests have demonstrated that wastes can be blended safely without adversely affecting their treatability.

Neutralization and Precipitation. Three 40 m^3 capacity reaction tanks will be provided for carrying out neutralization/precipitation reactions on wastes which do not require pretreatment by chemical oxidation/reduction. These tanks will also be of vertical, cylindrical configuration and equipped with conical bottoms. Three such tanks will provide optimum performance, flexibility and reliability for the following reasons:

- Three different batches of waste can be treated simultaneously without sacrificing optimum treatment efficiency for each batch Reagent dosages, reaction times and pH values can be tailored precisely to the particular batch of waste being treated in each reaction tank.

- The 40 m^3 reactor sizes match those of the largest waste storage vessels to simplify the transfer of wastes from storage to treatment and minimize the risk of spillages due to overfilling. Level controls in each tank will provide the additional safeguards required to prevent overfilling.

- The 40 m^3 reactors provide flexibility for blending compatible wastes from different waste storage tanks.

- Reliability is improved by the fact that one reactor can be shut down for maintenance without having a major impact on the overall treatment capacity of the system.

Where possible, neutralization and precipitation reactions will be carried out by combining compatible acidic and alkaline waste streams.

Provision will also be made for the addition of reagents (lime, caustic, sodium sulphide, ferric chloride) to assist in the precipitation reactions.

Exothermic reactions involving the neutralization of strong acids and alkalis will be carried out in one of the jacketed reaction tanks to enable the temperature rise of the mixture to be controlled during the reaction sequence. In addition temperature increases will be controlled, if necessary, by adjusting the rate of reagent addition.

Each of the three neutralization/precipitation vessels will also be capable of functioning as batch coagulation and solids settling vessels. This will be particularly useful for wastes which require an intermediate solids separation step between successive stages of precipitation.

In all cases, laboratory treatability tests will be used to predetermine the appropriate treatment recipe prior to the start of treatment (see p. 166).

Coagulation/Sedimentation. The inorganic treatment system will have the flexibility to enable coagulation and sedimentation of precipitated solids to be carried out either in the reaction tanks or in three separate 40 m^3 solids separation and sludge thickening vessels. It is anticipated that the precipitated solids will be flocculated and allowed to settle in the reaction tanks after precipitation is completed. The settled solids will be withdrawn to one of the sludge thickening tanks for further thickening by gravity. The thickening tanks will be cylindrical, conical bottom tanks to facilitate this process.

Three sludge thickening tanks are expected to provide optimum performance and flexibility for the following reasons:

- Separate tanks operating batchwise will enable sludges to be gravity thickened to the maximum extent possible prior to dewatering by pressure filtration.

- Separate tanks will enable sludges of different pH values and different compositions to be kept segregated where necessary. This will be important in cases where mixing two incompatible sludges (eg. aluminum hydroxide at pH 7 with cadmium hydroxide at pH 10) would cause some of the precipitated metals to redissolve due to the resulting pH change.

- This arrangement will also enable compatible sludges to be mixed in order to improve their dewaterability.

- The sludge thickening tanks will provide a source of thickened sludge for recycle to the reaction tanks. Recycle sludge will be used where required to enhance the precipitation reactions being carried out in the reaction tanks and improve the settling characteristics of the precipitated solids.

- This arrangement will enable sludges containing high concentrations of organic contaminants to be kept segregated for further treatment by incineration.

Where required suitable high molecular weight polyelectrolytes will be used to enhance the settling characteristics of the suspended solids.

Sludge Dewatering. Three plate and frame pressure sludge filters will be used to dewater thickened sludge from the sludge thickening tanks. A suitable filter aid such as diatomaceous earth will be used where required to enhance the dewaterability of the thickened sludge.

The filtrate from the sludge filters will be routed to one of seven intermediate storage tanks. The remaining filter cake will be sent to solidification. Filter cake which contains a high organic content will be sent to the incinerator for disposal. Laboratory leach tests carried out in advance of treatment will be used to determine whether the filter cake is suitable for solidification and disposal in the engineered landfill or whether it must be incinerated.

Three sludge filters will be required to handle the quantities of sludge anticipated and to provide the necessary operating flexibility. Each sludge thickening tank will be capable of feeding sludge to two of the three filters (one plus an alternate).

Intermediate Storage

Seven 40 m^3 capacity intermediate storage tanks will be provided for the purpose of storing partially treated process wastes.

The intermediate storage tanks will be designed to serve the following functions:

- o To provide an opportunity for difficult to treat or complex waste mixtures to be analyzed after the primary and/or secondary treatment steps have been completed to confirm the effectiveness of primary and secondary treatment.
- o To determine whether the waste requires repeated secondary treatment prior to effluent polishing.
- o To provide an opportunity to verify (if necessary)the required combination of effluent polishing steps needed to produce the best effluent quality.
- o To provide surge capacity and feed storage of partially treated wastes prior to effluent polishing.

The number and size of the intermediate storage tanks has been selected on the basis of providing sufficient storage for the partially treated batches processed during a single shift plus additional capacity for batches which must be stored longer pending the results of additional treatability testing if required.

Multiple tanks have been selected in favour of one large tank to enable difficult to treat or complex batches of waste to be segregated in the event that these should require retreatment prior to effluent polishing.

The intermediate storage tanks will be kept physically and functionally separate from storage tanks containing untreated wastes in order to eliminate the risk of recontaminating batches of waste which have been through primary and secondary treatment.

Effluent Polishing

After primary and/or secondary treatment, partially treated wastes will undergo final effluent polishing to ensure that the treated effluent is suitable for reuse onsite and is of a quality which is suitable for discharge by evaporation.

Effluent polishing will consist of a combination of the following unit processes:

- Granular media filtration - to reduce the concentrations of residual suspended solids and oil and grease.

- Activated carbon adsorption - to reduce the concentrations of residual dissolved organics (and selected inorganics).

- Reverse osmosis - to reduce the total dissolved solids concentration of the treated effluent, reduce the concentrations of residual dissolved heavy metals and other inorganic contaminants of concern and remove additional dissolved organic contaminants prior to reuse or discharge to atmosphere by evaporation.

- Evaporation - to reduce the total dissolved solids concentrations of treated effluents which are not suitable for final polishing by reverse osmosis.

The effluent polishing treatment unit processes have been selected to ensure that wastes receive treatment to the maximum extent possible prior to onsite reuse or discharge.

Additional space has been allocated inside the physical/chemical building to provide a degree of flexibility for adding other polishing steps (such as biological treatment) to the physical/chemical treatment plant.

Granular Media Filtration. A total of four granular media filters will be used to remove finely divided suspended solids and immiscible organics after primary and/or secondary treatment. Two filters each 50 m^3/h capacity will be used to filter partially treated effluents from the inorganic and aqueous/organic process systems. In order to provide the necessary processing flexibility and reliability, one filter will operate while the other is either in backwash or standby mode. The remaining two filters, each 25 m^3/h capacity, will be used to filter partially treated effluents from the miscellaneous waste treatment system.

Activated Carbon Adsorption. In order to maximize flexibility, reliability and performance, the physical/chemical plant will be equipped with four activated carbon adsorption units. Three equal sized units will each have a capacity of 50 m^3/h to match the treatment capacity of the granular media filters. Two of these units will operate in series. Two of the three units will be in operation at any one time. The third unit has been included to provide maximum operational flexibility as follows:

- The third (standby) unit will be brought into operation during periods when one of the operating units is down for carbon replacement.

- The third unit will also be used to treat effluents from the miscellaneous wastes treatment system in the event that these wastes require additional polishing for the removal of dissolved organic contaminants.

The fourth activated carbon unit will be smaller with a capacity of approximately 17 m^3/h. This unit will be designed to prepolish effluents from the aqueous/organic treatment system prior to further treatment for removal of inorganic contaminants or further polishing by activated carbon and reverse osmosis. This approach has been chosen for the following reasons:

- Batches of waste which are pretreated in the aqueous organic process train are expected to contain somewhat higher concentrations of dissolved organic contaminants compared to inorganic wastes.

- The prepolishing activated carbon unit is designed to reduce these high organic loadings in aqueous organic wastes before they enter the final effluent polishing steps or before they are treated for removal of inorganic contaminants.

- The system will be capable of applying three separate stages of activated carbon treatment in the case of difficult to treat wastes. This arrangement will enable dissolved organic contaminants to be removed in a stagewise manner and minimize the chance of process upsets which could occur due to contaminant breakthrough.

- The lower organic loadings to the final polishing units is expected to result in a reduction in the frequency of carbon replacement in these units.

Initially, all of the spent carbon from the activated carbon adsorption units will either be incinerated on site or, sent offsite for regeneration at an approved Facility. On site carbon regeneration options will be examined as required after start-up depending on the actual carbon usage. This approach is intended to avoid the high capital and operating costs associated with installing on site carbon regeneration Facilities until such equipment is justified based on operating experience.

Reverse Osmosis. The physical/chemical treatment plant will be equipped with two reverse osmosis (RO) modules each with a capacity of $25m^3/h$.

The RO treatment modules will operate in parallel. Each will be capable of polishing treated effluents from the inorganic and aqueous organic treatment systems for a range of mass balance scenarios from typical operation, which assumes a total average solids concentration in the feed to the physical/chemical plant and solidification plant of approximately 25.8 % by weight, to a high effluent scenario which assumes a total solids concentration of 10 % by weight.

As outlined previously (p. 119), under typical operating conditions, it has been estimated (based on the available waste profile date) that approximately 50% of the treated effluents from the activated carbon units will be suitable for further polishing by reverse osmosis (i.e. contain less than 3.5 % by weight Total Dissolved Solids (TDS)). The remaining batches of treated effluent which contain very high TDS concentrations will by pass the RO units either directly to solidification or to further polishing by evaporation (see Figure 2, p. 132).

The high effluent case on the other hand produces a scenario in which a much higher proportion of the treated effluents (75 to 80%) could potentially be suitable for polishing by RO. In this case, a relatively small proportion of the wastes would require evaporation. To provide maximum operational flexibility the design capacity of the RO units has been based on the high effluent case.

Normally one of the two RO units will be in operation at any one time. The second unit has been included to provide additional operational flexibility and reliability and, to provide additional RO treatment capacity as follows:

- The standby unit will operate during periods when the main operating unit is out of service for routine maintenance or unscheduled repairs.

- The second module will also be required for polishing effluents from the miscellaneous waste treatment system in the event that additional polishing is required prior to either on site reuse or discharge by evaporation. The combined treatment capacity of both RO treatment modules will therefore be 50 m^3/h which corresponds to the design capacity of the miscellaneous treatment system. (see p. 130)

- The second module will provide additional treatment capacity for retreating batches of waste which require retreatment in order to meet the requirements for on site reuse or discharge by evaporation.

Final Effluent Storage

Polished effluent from the reverse osmosis units will be discharged to one of five 320 m^3 capacity final effluent storage tanks. These tanks are designed to enable treated effluent to be held until water quality results from the laboratory have confirmed that the required effluent discharge values for all parameters have been achieved and the liquid effluent is suitable for either recycle or discharge by evaporation.

Five separate tanks each 320 m^3 in size have been chosen for the following reasons:

- Treated effluents are stored in batches of manageable size to facilitate retreatment in the event that this becomes necessary. Each tank will store a minimum of one day's accumulation of treated effluent.

- This arrangement of five tanks provides sufficient flexibility to enable treated effluents to be stored pending the results of laboratory analyses. This is necessary because the physical/ chemical laboratory may operate one shift per day while the physical/chemical plant may be required to operate additional shifts once the total quantity of inorganic special waste exceeds 50 000 t/a.

Evaporation

The evaporation system will consist of a feed forward triple effect forced circulation unit with two preheaters. This configuration has been chosen to maximize steam economy.

For maximum flexibility, the evaporators will be capable of operating in any one of three operating modes:

- condensing mode, where the evaporator effects are used to produce distilled water for recycling.
- venting mode, which discharges excess treated effluent from the Facility by venting steam from all three units.
- partial venting mode, which enables some steam to be condensed for recycle and the remainder to be vented as steam to the atmosphere.

The evaporators are designed to process up to 220 000 t/a of feed based on 8000 operating hours per year. Typically, the evaporator feed will consist of high TDS reverse osmosis rejects plus treated effluents from the physical/chemical treatment process which contain very high TDS concentrations (above 4 % by weight) that can not be handled by the reverse osmosis units. However, sufficient capacity has also been included in the design of the multiple effect evaporators and the 11 000 m^3 evaporator feed pond to cater to larger throughputs during abnormal throughput demands.

- The evaporator system in tandem with the reverse osmosis units will be capable of processing peak storm water flows of contaminated surface drainage after treatment in the miscellaneous treatment system.
- The system will also provide for two separate incinerator shutdowns per year each of 6 weeks duration. During these shutdown periods, a major portion of the total plant recycle water requirement will not be in use. The excess effluent will be stored in the evaporator feed pond during the 6 week shutdown. After start up, the evaporators will operate at increased capacity to catch up on

the evaporators will operate at increased capacity to catch up on the disposal of the excess effluents. The six week period is a conservative design basis, and incinerator shutdowns for maintenance will normally be much shorter than this.

The following additional features have been included in the design of the evaporators to maximize performance, safety, flexibility and reliability and ensure minimum impact on human health and the environment occurs as a result of the evaporator emissions.

- The quality of all evaporator feed streams will be checked prior to entering the evaporator feed pond. Any effluents which are unsuitable for evaporation will either be solidified (if scaling is likely to be a problem) or incinerated (if the problem relates to the presence of high organic concentrations). As an additional check, regular water quality analyses will also be carried out on samples from the evaporator feed pond itself. This approach will ensure that the evaporator emissions will always meet or better MOE requirements. The quality of the evaporator emissions is discussed further in Section 4.5.5 (p. 209).

- The evaporator feed pond and recycle pond can be used to store treated effluents and/or evaporator condensate during periods when local weather conditions are likely to cause icing in or around the Facility when the evaporator is operated in the venting mode.

- Similarly, the system has been designed so that when one evaporator effect is down for maintenance or cleaning, any excess effluent can be stored in the evaporator feed pond, some can be processed in the reverse osmosis units and the accumulated effluent can be evaporated in a reasonable time period when operations return to normal.

- The service of the three evaporator effects will be interchangeable for maximum operational flexibility and facilitate maintenance.

tanks along with condensate from the evaporators will be stored in a $5000 m^3$ capacity recycle water pond. This pond has been sized to accommodate two weeks recycle water requirements for the incineration, physical/chemical and solidification plants.

4.3.3 Aqueous Organic Treatment System

Primary Treatment Processes

Phase Separation. Wherever practical, immiscible organics will be allowed to separate in the aqueous organic waste storage tanks prior to further treatment of the recovered aqueous phase by physical/chemical methods. Any immiscible organic liquids or oily solids which separate during storage will be transferred to the organic tank farm.

Blending. Blending of aqueous organic wastes will also take place in the waste storage tanks. Laboratory treatability test information will be used as a basis for determining whether two or more wastes can be blended safely without adversely affecting their treatability.

Secondary Treatment Processes

Emulsion Breaking. Emulsion breaking will be carried out in two $25 m^3$ capacity conical bottom tanks. These tanks will operate in parallel to provide maximum flexibility and reliability particularly for batches of waste which require longer processing times. Organic containing solids which settle to the bottom of the emulsion breaking tanks will be sent for incineration. The demulsified liquid phases (aqueous and organic) will be separated by centrifugation.

Centrifugation. The centrifuge will be sized to separate aqueous organic mixtures at a rate of approximately $17 m^3/h$ after demulsification.

The use of a centrifuge will enable more efficient use to be made of the emulsion breaking tanks by reducing the time required to achieve efficient phase separation following the emulsion breaking step. The centrifuge will be capable of processing the contents of each emulsion breaking tank in approximately 1.5 hours. The organic phase recovered by centrifugation will be transferred to the organic tank farm prior to being incinerated. The recovered aqueous phase will receive additional treatment by dissolved air flotation. Where necessary centrifugation will also be used to separate solids which may be present in untreated batches of aqueous/organic waste prior to emulsion breaking.

The centrifuge has been conservatively sized to provide maximum performance and flexibility as follows:

- Sufficient capacity is available to enable some batches to be retreated, if necessary, prior to the dissolved air flotation step.
- Sufficient capacity is available to permit successive batches of waste to be kept segregated as they pass through the centrifuge and dissolved air flotation units. This feature is designed to improve the efficiency of downstream treatment processes.
- A moderate amount of equipment downtime can be tolerated without affecting the overall capacity of the system. This eliminates the need for a second centrifuge to provide standby capacity.

Dissolved Air Flotation. Dissolved Air Flotation (DAF) will be used to achieve additional removals of suspended (immiscible) organics and finely divided suspended solids which are not removed by centrifugation.

The DAF unit will be preceeded by a flocculation step to maximize the efficiency of air flotation.

To maximize the operating flexibility of the system, the DAF unit has been sized for the same capacity as the centrifuge (17 m^3/h) and will be capable of treating the aqueous phase from the emulsion breaking tank either directly or after centrifugation.

The oily "float" which is skimmed from the surface of the DAF unit will be sent to the organic tank farm prior to being incinerated. The treated effluent from the DAF unit will be routed to the prepolishing activated carbon unit, either directly or via the granular media filters to reduce the suspended solids loading prior to carbon adsorption. Alternatively, the discharge from the DAF unit may be directed to the inorganic reaction tanks prior to effluent polishing. In all cases, the required combination of processing steps will be determined in advance for each batch of waste based on laboratory treatability test information.

Activated Carbon Adsorption. As outlined previously (p. 151), a smaller 17 m^3/h capacity activated carbon unit will be dedicated to the aqueous organic process train for the purpose of prepolishing the partially treated aqueous organic effluents prior to further treatment. The capacity of this unit has been selected to match the capacity of the centrifuge and DAF units. The rationale for including this prepolishing activated carbon unit has been outlined on page 151.

Intermediate Storage

Partially treated wastes from the aqueous organic treatment system will be discharged into a single 40 m^3 intermediate storage tank to await further treatment.

Effluent Polishing

After secondary treatment, the aqueous organic wastes will be polished by granular media filtration, by activated carbon adsorption and finally by reverse osmosis. The polished effluent will discharge to the final effluent storage described on page 154.

The effluent from the dissolved air flotation unit will be filtered, if necessary, to reduce the solids loading on the prepolishing activated carbon unit.

All of the effluent polishing units, except the prepolishing activated carbon unit, have been selected and sized to handle pretreated wastes in batches from both the aqueous organic and inorganic process trains. This approach is intended to maximize the efficiency of equipment use within the plant by minimizing any unnecessary equipment duplication between processing systems.

4.3.4 Miscellaneous Treatment System Primary/Secondary Treatment Processes

Equalization. The miscellaneous wastes will be combined in a single 80 m^3 capacity equalization tank prior to treatment. The equalization tank is designed to fulfill the following functions:

- To blend leachate and surface drainage prior to treatment in the event that it becomes necessary to treat these flows simultaneously.

- To provide sufficient surge capacity to equalize the flow rate of leachate and/or surface drainage through the miscellaneous treatment system.

- To provide a reservoir for the storage of small volumes of miscellaneous wastes prior to batch treating these wastes.

- To provide a reagent addition and mixing point upstream of the main reaction tank for additional processing flexibility.

The equalization tank also serves as a backwash holding tank for the granular media filters thus eliminating the need to provide additional equipment specifically for this purpose.

Neutralization/Precipitation. Miscellaneous wastes from the equalization tank will be pumped to a 20 m^3 capacity reaction tank. Reagents will be metered into the reaction tank either in proportion to the flow rate of miscellaneous waste into the reaction tank or in response to a pH control signal. The appropriate reagent types and dosages will be determined in advance based on laboratory tests and rechecked periodically during the operation of the miscellaneous process system to ensure consistency and reliability of operation.

The reaction tank will be capable of carrying out oxidation/reduction neutralization and precipitation reactions as required to treat the types of contaminants present in the miscellaneous waste.

The design of the reagent feed systems will be sufficiently flexible to enable additional reagent feed points to be added either before the reaction tank (in the equalization tank) or after the reaction tank (in the clarifier centre well) as dictated by the processing requirements of the miscellaneous wastes.

Flocculation/Sedimentation. The discharge from the reaction tank will be directed to a solids contact type reactor clarifier. The clarifier will be sized for the design capacity of the miscellaneous waste treatment system (50 m^3/h). Polyelectrolyte will be added to the clarifier centre well to maximize the efficiency of solid/liquid separation. Sludge which accumulates in the bottom of the clarifier will be discharged intermittently to the sludge thickening tanks in the inorganic waste process train en route to the sludge dewatering filters.

This arrangement offers a number of advantages related to the performance flexibility and cost of the miscellaneous treatment system.

- Solids separation, sludge thickening and sludge storage functions are combined in one unit thus eliminating the need to provide additional separate items of equipment for each of these functions.

- Sludge recycle also takes place within the reactor clarifier. This minimizes the potential operating problems associated with floc break up which can occur in systems which rely on external sludge recycle.

- Reagents other than polyelectrolyte can be added to the centre well of the clarifier thereby enhancing the operational flexibility of the miscellaneous treatment system.

Sludge Dewatering. Excess sludge which accumulates in the bottom of the clarifier will be withdrawn periodically to maintain a constant sludge blanket depth. Sludge dewatering will be carried out using one of the three sludge filters in the inorganic treatment process train. This approach is practical and cost effective because of the small volumes of sludge which are expected to result from the treatment of relatively dilute mixtures of landfill leachate and/or surface drainage. Equipment requirements are minimized by eliminating the duplication of sludge dewatering capability between process systems.

Effluent Polishing

Granular Media Filtration. Clarifier overflow will first be filtered to remove finely divided suspended solids which are not removed by the flocculation/clarification step. Two granular media filters have been provided specifically for this purpose each designed to treat 50% of the design flow of the miscellaneous treatment system or 25 m^3/h. This arrangement has been designed to provide adequate operational flexibility and reliability at minimum cost recognizing that approximately 80% of the design capacity of the miscellaneous treatment system has been set aside for the treatment of site surface drainage which may never require treatment. Similarly, it is not known whether landfill leachates will require physical/chemical treatment prior to reuse or disposal.

Activated Carbon Adsorption. As indicated on p. 151, additional activated carbon treatment capacity is available in the inorganic waste treatment system for filtered effluents from the miscellaneous treatment system which require additional polishing for the removal of dissolved organic contaminants. The capacity of the standby unit matches that of the miscellaneous treatment system 50 m^3/h. This approach is cost effective because it eliminates the need to provide a separate, dedicated activated carbon unit in the miscellaneous treatment system without jeopardizing the performance or reliability of the system for treating wastes to the maximum extent possible prior to reuse or discharge.

Reverse Osmosis. As indicated on p. 153, additional reverse osmosis treatment capacity is available in the inorganic process system in the event that the effluent from the miscellaneous waste treatment system requires additional polishing for the removal of dissolved inorganic contaminants prior to reuse or evaporation. This approach enables all of the effluent polishing steps to be available to the miscellaneous treatment system to maximize the treatment performance of this system without the high cost of providing separate dedicated polishing units for this purpose.

Final Effluent Storage

Treated effluent from the miscellaneous treatment system can either be discharged to the 11 000 m^3 evaporator feed pond or discharged to the recycle water pond after final polishing. Water quality analysis will be carried out prior to reusing or discharging the treated effluent from the Facility by evaporation.

4.4 PLANT OPERATION

The following sections outline the physical/chemical plant operating and control philosophies, safety features and the emergency response procedures of the process design which will ensure that the plant performs as designed and is capable of operating in a safe and environmentally sound manner during normal operation and plant upset conditions.

General

Figure 9 provides a schematic overview of the operating philosophy of the physical/chemical plant.

The key operating features of the physical/chemical treatment system which are illustrated in Figure 9 are summarized as follows.

- The physical/chemical treatment plant will initially operate 8 hours per day 5 days per week 50 weeks per year. Additional hours per day will be worked as the waste quantities increase.

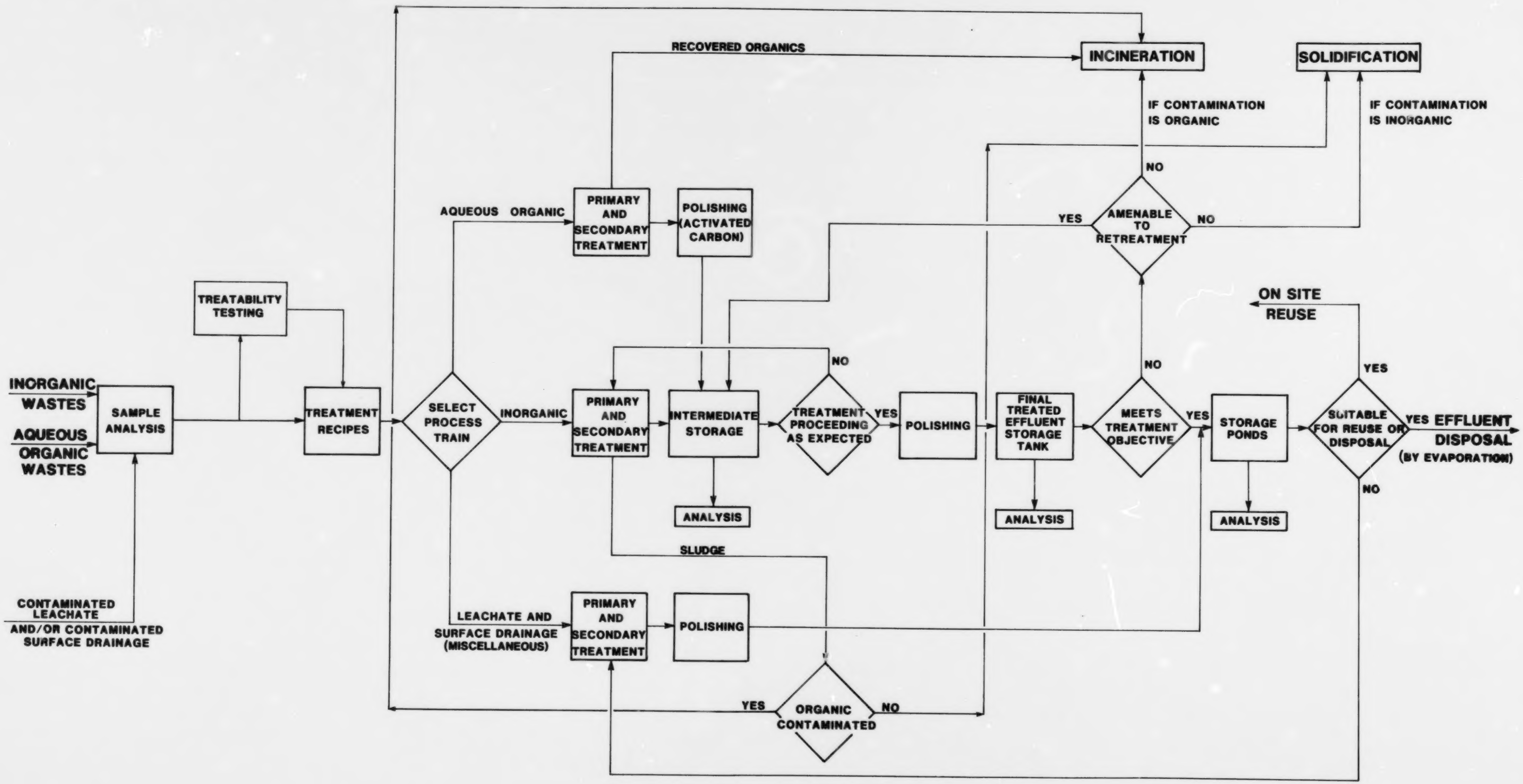
INORGANIC WASTES
AQUEOUS ORGANIC WASTES
CONTAMINATED LEACHATE AND/OR CONTAMINATED SURFACE DRAINAGE
SAMPLE ANALYSIS
TREATABILITY TESTING
TREATMENT RECIPES
SELECT PROCESS TRAIN
AQUEOUS ORGANIC
INORGANIC
LEACHATE AND SURFACE DRAINAGE (MISCELLANEOUS)
PRIMARY AND SECONDARY TREATMENT
POLISHING (ACTIVATED CARBON)
RECOVERED ORGANICS
INCINERATION
SOLIDIFICATION
IF CONTAMINATION IS ORGANIC
IF CONTAMINATION IS INORGANIC
PRIMARY AND SECONDARY TREATMENT
INTERMEDIATE STORAGE
ANALYSIS
NO
TREATMENT PROCEEDING AS EXPECTED
YES
POLISHING
FINAL TREATED EFFLUENT STORAGE TANK
ANALYSIS
MEETS TREATMENT OBJECTIVE
YES
NO
AMENABLE TO RETREATMENT
YES
NO
NO
STORAGE PONDS
ANALYSIS
SUITABLE FOR REUSE OR DISPOSAL
YES
ON SITE REUSE
YES
EFFLUENT DISPOSAL (BY EVAPORATION)
NO
SLUDGE
PRIMARY AND SECONDARY TREATMENT
POLISHING
ORGANIC CONTAMINATED
YES
NO

FIGURE 9

PHYSICAL/CHEMICAL TREATMENT PLANT OPERATING PHILOSOPHY SCHEMATIC

- All surface drainage from the central operating area and potentially contaminated drainage from the landfill area will be collected and analyzed to determine whether treatment is required. Landfill leachate will also be monitored to determine whether it requires treatment. If treatment is required and the quantities involved are small, these wastes can be treated batchwise in the inorganic treatment system. Otherwise, these wastes will be treated in the miscellaneous treatment system.

- In the event that a large volume of surface drainage becomes contaminated and must be treated, the miscellaneous waste treatment system will be operated continuously (24 h/d) until the problem is resolved.

- Sample analyses and treatability test information will be used to establish treatment recipes for wastes prior to physical/chemical treatment.

- The physical/chemical treatment processes have been designed to achieve a staged reduction in contaminant concentrations through primary treatment, secondary treatment and effluent polishing.

- Quality control checks will be carried out during the treatment sequence to ensure that treatment is proceeding as planned.

- Quality control checks will be carried out after treatment to confirm that the treated effluent is suitable for reuse or discharge.

- The physical/chemical treatment systems will be designed and operated to enable treated effluents to be reused on site to the maximum extent possible.

- Treated effluents which fail to meet the required treatment objective for either reuse or discharge to atmosphere by evaporation may either be

- retreated in the physical/chemical plant or,
- solidified if the residual contaminants are inorganic in nature or,
- incinerated if the residual contaminants are organic in nature.

Treatability Testing. Operation of the physical/chemical treatment plant is based on the requirement that each treatment step will be determined in advance based on the results of laboratory scale treatability tests. No waste will be treated unless test data are available which specify the optimum combination of treatment steps required to produce the desired effluent quality and which demonstrate that the desired effluent quality can be achieved.

Batches of waste destined for physical/chemical treatment will have a treatment recipe assigned in advance of arrival at OWMC's Facility based on tests which have been carried out on prior samples obtained from the waste generator. Once an optimum treatment recipe has been developed for each generator's waste, the same recipe will be applied wherever possible to successive batches of waste from the same generator. Additional treatability testing will be done only if the fingerprint analyses indicate either a change in waste characteristics has occurred which would not be accommodated by the established treatment recipe or, if the established treatment recipe had failed to produce satisfactory results for the previous batch of waste treated. All wastes will be subjected to fingerprint analysis on arrival at the Facility.

Additional treatability tests will also be carried out in advance of mixing any two potentially compatible wastes together to ensure that the operation can be done safely, to verify that the treatability of the combined waste is not adversely affected and to establish the optimum treatment recipe for the new batch of combined waste.

The laboratory will assign the appropriate treatment recipe for each waste stored in the inorganic tank storage area. The treatment recipe will provide the physical/chemical plant operators with the following information:

- Location of waste in tank storage area.
- Size of batch and type of waste.
- The treatment steps to be applied to the waste and the order of their application.
- The type and quantity of reagents to be added at each stage of the treatment process and the order of their addition.
- Key control parameters which must be maintained during each stage of the treatment process such as reaction times, settling times, pH, oxidation/reduction potential, and temperature.
- The types of analyses which must be carried out at intermediate stages of treatment to verify that treatment is proceeding as expected.
- Special operating procedures or safety precautions which must be observed during the handling and treatment of a particular batch of waste.
- Special emergency procedures which must be followed in the event of a spillage.
- Special requirements for flushing waste transfer lines after transferring a particular batch from storage to treatment.

Once the physical/chemical plant operators have received the treatment recipe for a particular waste they will schedule its treatment in a safe manner consistent with achieving the most effective use of equipment and which will enable them to monitor each batch through the various stages of treatment.

Process Control Philosophy. The physical/chemical plant process control system will provide the plant operators with the flexibility to control major items of process equipment including associated pumps and valves either centrally from the control room in the physical/chemical building or locally from a position at the equipment itself depending on the operating function being carried out.

The physical/chemical plant control philosophy has been developed in accordance with the following general principles:

- For maximum safety, efficiency and reliability, operation of all valves and pumps to transfer waste from storage tanks to the reaction tanks, including line flushing where required, will be controlled and monitored from the control room.

- For efficiency and convenience the reaction tanks will be controlled locally.

- Operation of all valves which determine the direction and destination of waste flows through subsequent stages of physical/chemical treatment will be from the control room.

- The ability for local start and stop will be provided for all mechanical equipment. Local start functions will only be permitted by a signal from the control room.

- Local operations will be co-ordinated and monitored from the control room for maximum safety, efficiency and reliability.

The following points summarize the remaining key features of the control philosophy which apply to all treatment processes in the physical/chemical plant.

- The control room will be located in a strategic location on the second floor of the building between the physical/chemical and solidification process areas.

- The process control equipment will be a micro processor based distributed control system. The data management system will be a central computer system with distributed intelligent access.

- All treatment functions and waste transfer operations will be operator initiated using a keyboard interface. Process monitoring will be by cathode ray tube (CRT) display.

- All waste treatment recipes will be stored in the data management system for display on the CRT.

- All alarm conditions will be indicated by audible and visible annunciation in the control room via the CRT display.

- Local alarm annunciation will be provided where there is a possibility of local danger to operating personnel.

- All safety showers will alarm if activated.

- Key process measurements can be stored short term (24 hours) in the control system or long term in the data management system.

- Feedback signals will indicate the start/stop status of all rotating equipment (pumps and agitators) in the control room.

- Feedback signals will also show the position (open or closed) of all remote control valves in the control room.

- All process control parameters will be indicated locally as well as in the control room.

- Trend recorders will be available and a process measurement such as pH can be connected to one of these if desired.

- Printers will be available in the control room for generating hard copies of reports and information such as waste treatment recipes.

OPERATIONAL SAFETY

The following operational safety features have been included in the design and operation of the physical/chemical treatment plant to ensure that it is capable of operating with minimal risk to occupational health and to the environment.

Process Fume and Dust Control

- All waste storage process reagent storage and treatment processes within the physical/chemical building will be carried out in vessels which are totally enclosed and vented. Vented air will be scrubbed before it is discharged from the physical/chemical building to the atmosphere.

- The storage tanks and reaction tanks will be under slight negative pressure due to the ventilation system. This will prevent fugitive gaseous emissions from escaping into the building.

- The top inspection hatches on each reactor will normally remain closed during the treatment sequence. Sampling will be carried out from sampling valves designed to minimize the risk of operator exposure to the tank contents.

- A separate booster fan will be provided in the ventilation duct from each reaction tank. This fan will start automatically if the inspection hatch is opened during the reaction sequence thus ensuring that fumes and vapours do not escape the tank to endanger the operator.

- The main ventilation air fans will be duplicated to guard against mechanical failure and the entire ventilation air collection and scrubbing system will be on emergency power supply to maintain full ventilation capability during power outages.

Building Ventilation

- The physical/chemical building will be ventilated separately from the process equipment and tanks. Therefore, any gaseous emissions which escape the process fume and dust collection system will be removed from the physical/chemical plant by the general building ventilation system.

- The physical/chemical control room will be internally pressurized with a separate clean air supply.

- Process reagent storage tanks and transfer pumps will be housed in separate enclosed and ventilated areas inside the physical/chemical building. This approach has been adopted for the following reasons:

  - to ensure that reagents are contained in the event of spills or leaks and that spills or leaks of potentially uncompatible reagents are kept segregated.
  - to ensure that fugitive dusts, odours and fumes are contained and kept segregated from the remainder of the physical/chemical building.

Spill Protection

- Minor spills or leaks from process tanks and pump seals will be contained by curbs around the base of each tank.

- An overflow collection tank will be provided for each group of six waste storage tanks to contain spillages in the event of failure of the tank level control and alarm systems during waste transfer operations. The six tanks within the group will be reserved for compatible wastes.

- Large spillages resulting from tank rupture or overfilling will be collected in segregated sumps also designed to collect floor washwater. Any such spills will be contained within the physical/chemical building. Alarms will alert the operators that a spillage has occurred.

Emergency Power Supply

- The plant control and status monitoring system is connected to the emergency power supply along with the ventilation fans and ventilation air scrubbing systems.
- All systems on normal power will be restarted in an orderly sequence by the plant operators.

Fire Protection

- Areas of the physical/chemical building which store or treat potentially flammable aqueous/organic mixtures will be protected by foam fire protection systems which will activate automatically in the event of a fire.
- Fire walls will be provided between organic and inorganic treatment systems.
- The inorganic waste storage and physical/chemical processing areas will be protected by a sprinkler system.
- The control room will be protected by a Halon fire extinguishing system.

Additional Safeguards

- Gas analyzers will sample the ventilated air from each reaction tank for the presence of toxic gases (eg. hydrogen cyanide and hydrogen sulphide). An alarm will alert the operators of a potential upset condition which has resulted in gas formation.

- All inorganic waste storage tanks will be equipped with temperature indicators and remote alarms to warn the operators in the event that incompatible wastes have been mixed causing an exothermic reaction.

- Emergency eyewash and shower stations will be provided at strategic locations at all levels in the physical/chemical building.

- Emergency escape routes will be provided from the top floor via four access stairways located in each corner of the physical/chemical building or via the solidification building.

TYPICAL TREATMENT SEQUENCE

The following paragraphs illustrate the manner in which a typical waste will likely be treated from the time of its arrival at OWMC's Facility until the completion of physical/chemical treatment. Figure 2, page 132, is a pictorial flow diagram that shows the physical/chemical treatment systems. For discussion purposes, it is assumed that the waste to be treated is sludge from a metal plating waste treatment facility which contains cyanide, heavy metals including hexavalent chromium and minor amounts of unspecified dissolved organics (less than 1%). The sludge is also assumed to be in the form of a non pumpable filter cake containing 30% solids (70% moisture) and has been shown, by laboratory scale solidification and leach testing to require physical/chemical treatment prior to solidification and landfilling.

Prior to its arrival at the Facility detailed analysis and, treatability testing will be carried out on samples of the sludge. If similar wastes from the same generator have been treated previously at the Facility, the treatment recipe which has already been developed for this waste will be reused. Additional treatability tests will be carried out only if the characteristics of the waste to be treated are significantly different from those of the previous batch.

On its arrival at the Facility, a sample of the waste will be taken for fingerprint analysis to verify its identity. Once cleared, the truck will be directed to the proper unloading station.

As a first step in the treatment process the waste will be reslurried using recycle water to 5 to 15 % by weight solids, to render it pumpable and make it suitable for subsequent physical/chemical processing. This will be carried out in the unloading basin during the unloading process or, if size reduction is required, in the solidification plant. The resulting dilute sludge mixture will then be transferred to one or more of the waste storage tanks to await subsequent treatment.

From the waste storage tanks, the mixture will be transferred into one or more of the oxidation reduction reaction tanks to start the secondary treatment processes. First, cyanide oxidation will take place to destroy free and complexed cyanides in the sludge mixture. This will be accomplished by adjusting the pH of the mixture (likely to around pH 10 or 10.5) and adding the appropriate quantity of sodium hypochlorite. All reagent additions will be initiated locally by the reactor operator.

Reagent dosages and reaction conditions (pH, oxidation potential and reaction time) will be dictated by the treatment recipe and set by the reactor operator. Second stage oxidation of cyanate to nitrogen and carbon dioxide will then be carried out by reducing the pH of the mixture (likely to around pH 8.5) with sulphuric acid and adding additional hypochlorite. Again, the actual reagent dosages and reaction conditions used will be determined from the treatment recipe. At the completion of the cyanide oxidation step a sample of the mixture will be obtained for laboratory analysis to verify that treatment is proceeding as expected.

Following cyanide oxidation, the pH of the mixture will be reduced to approximately pH 2.0 with sulphuric acid. Sodium bisulphite will be metered into the reaction tank in accordance with the treatment recipe to reduce hexavalent chromium to trivalent chromium. This will be carried out in the same reactor. After the prescribed reaction time, a sample of the waste will be collected for laboratory analysis to verify that the chromium reduction step has proceeded to completion.

Following chromium reduction the pH of the mixture will be raised (likely to between 8 and 9.5 depending on the treatment recipe) to precipitate trivalent chromium and other dissolved heavy metals as metal hydroxides. This neutralization/precipitation reaction will be carried out using either lime, sodium hydroxide or both depending on the treatment recipe. If the treatment recipe indicates the need for additonal precipitation steps using sodium hydrosulphide and/or ferric chloride then these steps will also be carried out in the same reactor.

At the completion of the precipitation reactions, flocculation and solids separation steps will be carried out. If possible, these steps will also be carried out in the same oxidation/reduction reactor. However, if this reactor is required for processing subsequent batches of waste, then the sludge mixture would be pumped into the sludge thickening tanks for flocculation and solids separation. These steps will involve adding the appropriate dosage of polyelectrolyte to the waste mixture, stirring for a specified period of time and then allowing the flocculated solids to settle to produce a clear supernatant and a thickened sludge. If necessary, the partially thickened sludge will then be transferred from the reactor into one of the sludge thickening tanks for further settling prior to dewatering and the clear supernatant will be transferred into one of the intermediate storage tanks prior to final polishing.

The thickened sludge from the sludge thickening tanks will be pumped through one of three sludge filters to produce a treated filter cake for solidification and landfilling. The filtrate from the sludge filters will be added to the clear supernatant in intermediate storage. At this point, additional samples will likely be collected from the intermediate storage tank for laboratory analysis to confirm that primary and secondary treatment have been completed as planned. If necessary the contents of the intermediate storage tank can be returned to one of the reaction tanks for additonal treatment.

If the organic content of the treated sludge is too high to enable it to be directly solidified and landfilled, the dewatered solids will be discharged into a portable container for treatment by incineration.

Partially treated effluent from the intermediate storage tank will then be polished, first by granular media filtration to remove any finely divided suspended solids which may be present, then by activated carbon adsorption to remove dissolved organics, organometallic complexes and some stable cyanide complexes (eg. iron cyanide) which may not have been destroyed by chemical oxidation.

Following activated carbon treatment the effluent will be given final polishing by reverse osmosis (RO) to remove dissolved solids including salts, residual heavy metals, residual metal cyanide complexes and organics. The concentrated rejects from the RO units will either be solidified and landfilled or incinerated depending on the concentrations of organics present. The clean discharge from the reverse osmosis units will be transferred to one of the final effluent storage tanks for final water quality checks before being discharged into the recycle water pond. Excess treated effluent will be discharged from the Facility by evaporation.

4.5 SYSTEM PERFORMANCE

4.5.1 Introduction

The following sections serve to demonstrate the capabilities of the physical/chemical treatment system for removing and/or detoxifying a range of typical inorganic and organic contaminants which may be present in the inorganic wastes requiring physical/chemical treatment.

Contaminant species which are currently of concern to the Ontario Ministry of the Environment (MOE) have been chosen to illustrate the performance capabilities of the proposed physical/chemical treatment system prior to discharge by evaporation. The current MOE Guidelines for the Control of Industrial Waste Discharges in Ontario (Ref: MOE[36]) for example, provide one yardstick against which the expected performance of the physical/chemical treatment system can be gauged. The data and information presented on pages 180 to 208 show that the proposed system is capable of achieving the lowest residual contaminant concentrations achievable using existing best available technology. As indicated in Table 7 (p. 182) the proposed treatment system is capable of achieving residual contaminant concentrations before final discharge by evaporation, which are equal to, and in some cases significantly better than, the current MOE guidelines. This will enable the treated effluents to be reused on site to the maximum extent possible thereby minimizing the total quantity of treated effluent requiring evaporation.

The evaporation step will result in a further decrease in the concentrations of residual inorganic contaminants which are discharged from the Facility as steam. Non-volatile inorganic components (such as dissolved salts) which are present in the feed to the evaporator will remain in the evaporator residues to be solidified and disposed of in the engineered landfill.

Except for phenol, the data in Table 7 deal almost exclusively with inorganic contaminants. Organic contaminants are dealt with in detail in a separate subsection beginning on page 202. The performance of the proposed physical/chemical treatment system for removing organic contaminants is important, because a portion of the residual organics which are present in the evaporator feed will volatilize in the evaporator and be discharged with the steam. Data and information presented in the section on treatability of organics (p. 202 to 209) demonstrate that the physical/chemical treatment system is capable of achieving very effective removal of a wide range of immiscible and dissolved organic contaminants of concern. The proposed system design will ensure that the concentrations of residual organics in the treated effluents prior to evaporation are well below the levels which are likely to be of concern from a human health or environmental impact point of view as follows:

- o Batches of wastes which contain high concentrations of organics which are not amenable to treatment by physical/chemical methods will be incinerated (p. 17).

- Batches of waste or treated residues which contain unacceptably high concentrations of organics after physical/chemical treatment will either be retreated or incinerated (p. 15).

Calculated evaporator emission data (Table 25, p. 210) indicate that contaminant concentrations will be many orders of magnitude lower than the current MOE emission standards, tentative standards, guidelines and provisional guidelines (Ontario Research Foundation[52]) and are much less than the concentrations which correspond to a one-in-one million cancer risk for carcinogens or established acceptable daily intake values (ADIs) for non-carcinogens (Environ[53]). The data presented in Table 25 are discussed further on pages 209 to 213.

The performance capabilities of the proposed physical/chemical treatment system are summarized in Sections 4.5.3 to 4.5.4 beginning on page 181. Section 4.5.2 which follows, outlines some of the factors which influence the accuracy of these performance predictions.

4.5.2 Status of Data

The performance of the physical/chemical treatment system as a whole can only be judged by assessing the capability of the system for removing specific chemical contaminants which are expected to be present in measurable concentrations in the untreated wastes. Due to the nature of all physical/chemical (and biological) treatment processes, it is not possible to generalize about percentage removals of all contaminants together. The removal efficiency which is achievable for each contaminant in a complex waste mixture will be uniquely dependent on a number of interrelating factors such as:

- the nature of the contaminant,
- its concentration in the untreated waste,
- the presence (or absence) of other contaminants in the waste mixture, and
- the type of treatment being applied.

Performance data are available for a number of inorganic and organic parameters of concern. It is important to emphasize that there is significant variability in these data for different treatment applications, different waste types and varying influent contaminant concentrations. The data summarized previously in Tables 4, 5 and 6 and in subsequent tables provide some insight into this variability.

Reasonable estimates can be made for some parameters (primarily inorganics) where data are available. However, it is not possible to accurately predict the performance of the proposed physical/chemical treatment system for the entire range of contaminants which could be present in the inorganic and aqueous organic wastes which are expected to require physical/chemical treatment. There are a number of reasons for this (Shuckrow et al[24]):

- Most available data on specific compound removal has been generated in laboratory and pilot scale experimental studies rather than from full scale operating systems.

- Furthermore, much of the experimental data on chemical treatability has been generated from pure compound systems. Removal from multi-component systems may differ substantially.

- Limited specific information is available through vendors because much of their work is considered proprietary and/or confidential.

- High analytical costs associated with specific compound identification has restricted the data base.

Final effluent concentrations are generally easier to predict for inorganic contaminants than for organics because more treatability data are available on inorganics and removal efficiencies of inorganics are less effected by influent concentrations. Data from European physical/chemical treatment facilities such as the HIM facility in Frankfurt, West Germany are of some assistance with respect to establishing expected concentrations of inorganic contaminants after primary and secondary treatment but since none of these facilities incorporates effluent polishing steps, it is not possible to obtain equivalent results after effluent polishing.

The concentrations of specific organic contaminants in the treated effluent from the physical/chemical plant are more difficult to predict for the following reasons:

- The treatability of organic contaminants by physical, chemical and biological methods is highly dependent on the types and concentrations of organics present in the untreated wastes. There is a general lack of contaminant specific data from waste generators on the types and concentrations of contaminants present in their wastes.

- Treatment technology performance and operating data for industrial process wastes containing a variety of organic pollutants are usually reported using a surrogate parameter such as total organic carbon or chemical oxygen demand. Specific compound removal data are available for only a very limited number of organic contaminants (Shuckrow et al[24]). As indicated on p. 178, much of this data has been generated from bench and pilot scale testing of pure compound systems.

- Existing European hazardous waste treatment facilities which are similar to OWMC's proposed Facility do not measure specific organic contaminant concentrations in their treated effluents. Therefore, it is not possible to cross-check and verify the data which are available in the literature based on experience in similar facilities in Europe.

To address these problems, a number of features have been incorporated into the design and operating philosophy of the physical/chemical system to ensure that the plant will perform in a manner which will ensure acceptable levels of risk to human health and the environment. The following sections outline the expected performance of the physical/chemical treatment system for chemically stablizing, detoxifying and/or concentrating a range of inorganic and organic contaminants which may be present in wastes requiring physical/chemical treatment.

4.5.3 Removal of Inorganics

Table 7 presents expected concentrations for a number of specific contaminants which may be present in the treated effluents from the physical/chemical plant. These parameters have been chosen for illustration purposes to indicate the levels which are expected to be present in the treated effluents prior to reuse on site or discharge by evaporation. A majority of the parameters listed in Table 7 represent contaminants for which the Ontario Ministry of the Environment (MOE) have established discharge objectives. Table 7 also presents the Objectives for Discharge to a Municipal Sewer and the MOE Provincial Water Quality Objectives. These objectives provide a yardstick against which the expected performance of the physical/chemical treatment systems can be gauged particularly with respect to inorganic contaminants of concern.

The expected effluent concentrations presented in Table 7 have been developed from an assessment of treatability data available in the literature along with data on the performance of the primary and secondary treatment steps from the HIM physical/chemical treatment facility in Frankfurt, West Germany. However, in order to verify these performance expectations and obtain data on additional organic and inorganic contaminants of concern, it will be necessary to carry out treatability tests on actual samples of waste. As outlined previously in Section 4.4, (p. 166), provision has been made in the design and operation of the proposed physical/chemical plant to enable treatability tests to be carried out on generators' wastes in advance of full scale treatment.

TABLE 7
MINIMUM CONCENTRATIONS ATTAINABLE FOR KEY PARAMETERS IN TREATED EFFLUENT FROM PHYSICAL/CHEMICAL PLANT

PARAMETER(1)	EXPECTED CONCENTRATIONS AFTER PRIMARY/SECONDARY TREATMENT AND FILTRATION (13)	EXPECTED CONCENTRATIONS AFTER POLISHING BY ACTIVATED CARBON (13)	EXPECTED CONCENTRATIONS AFTER POLISHING BY ACTIVATED CARBON AND REVERSE OSMOSIS (5, 13)	OBJECTIVES FOR DISCHARGE TO A MUNICIPAL SEWER	MOE OBJECTIVES FOR THE CONTROL OF INDUSTRIAL WASTE DISCHARGES IN ONTARIO(6)	MOE PROVINCIAL WATER QUALITY OBJECTIVES
Biochemical Oxygen Demand (BOD_5)	50	25	15	500	15	Not Specified
Suspended Solids	15	15	ND(12)	500	15	Not Specified
Oil and Grease	10	10	5	15	15	See Note (11)
Phenol	1.0	0.02	0.02	1.0	0.02	0.001
pH	7-10	6-8.5	6-8.5	6.0-10.5	5.5-9.5	6.5-8.5
Phosphate (As P)	10	10	1.0	100	1.0	0.1
Ammonia (As N)	5	5	1.0	Not Specified	10.0	0.02
Temperature (°C above receiving water)				65	11	10
Sulphate	Included in TDS	Included in TDS	Included in TDS	1500(2)	See Note (3)	Not Specified
Chloride	Included in TDS	Included in TDS	Included in TDS	1500(2)	See Note (3)	Not Specified
Chlorine				Not Specified	Not Specified	0.002
Total Dissolved Solids (TDS)	< 7 wt%	< 7 wt% (14)	< 800	See Note (3)	See Note (3)	See Note (7)
Aluminum	0.1	0.1	0.02	50	1.0	Not Specified
Arsenic	0.1	0.1	0.05	1.0	1.0	0.1
Barium	1.0	1.0	1.0	5.0	1.0	Not Specified
Beryllium	0.01	0.01	0.01	Not Specified	Not Specified	1.1 or 0.011(8)
Cadmium	0.05	0.01	0.001(4)	2.0	0.001	0.0002
Chromium	1.0	1.0	0.05	5.0	1.0	0.1
Copper	0.5	0.3	0.1	5.0	1.0	0.005
Cyanide (As HCN)	0.5	0.3	0.1	1.0	0.1	0.005
Fluoride	10.0	10.0	1.0	10.0	2.0	Not Specified
Hydrogen Sulphide				Not Specified	Not Specified	0.002
Iron	1.0	1.0	0.1	50.0	1.0	0.3
Lead	1.0	1.0	0.1	5.0	1.0	0.025 to 0.005(9)
Manganese	1.0	1.0	0.5	Not Specified	1.0	Not Specified
Mercury	0.01	0.005	0.001(4)	0.1	0.001	0.0002(4)
Nickel	1.0	1.0	0.05	5.0	1.0	0.025
Selenium	0.7(10)	0.1	0.1	Not Specified	Not Specified	0.1
Silver	0.1	0.05	0.05	Not Specified	Not Specified	0.0001
Tin	1.0	1.0	1.0	5.0	1.0	Not Specified
Zinc	1.0	1.0	0.05	5.0	1.0	0.03

Notes: See p. 183

EXPLANATORY NOTES TO TABLE 7

1. All concentrations are in mg/L unless otherwise noted.

2. Negotiable with Municipality.

3. As low as possible consistent with best available practical technology.

4. These concentrations will be difficult to achieve on a consistent basis even with effluent polishing.

5. Batches of waste which contain residual concentrations of any contaminants which are in excess of the discharge objectives will either be solidified or incinerated depending on the nature of the contamination.

6. As target effluent concentrations become lower, increased demands will be placed on the solidification and incineration processes to treat batches of waste which fail to meet effluent discharge standards. (See Note 4).

7. Must not increase ambient total dissolved solids (in receiving water) by more than 1/3.

8. Objective is 1.1 mg/L of beryllium where water hardness is greater than 75 mg/L of $CaCO_3$ and 0.011 mg/L where water hardness is less than 75 mg/L of $CaCO_3$.

9.

Alkalinity mg/L as $CaCO_3$	Maximum Lead Concentration (mg/L)
up to 20	0.005
20 to 40	0.010
40 to 80	0.020
greater than 80	0.025

10. Assumes maximum concentration of selenium in untreated waste is 1.0 mg/L.

11. Not detectable as a visible film, sheen or discolouration on the water surface. Not detectable by odour. Not cause tainting of edible aquatic organisms.

12. Not detectable. Cartridge filters upstream of the reverse osmosis packages will remove essentially all of the residual suspended solids prior to reverse osmosis treatment.

13. Expected concentrations are based on judgemental assessment of the operating data of existing waste treatment facilities. Ref: USEPA[11], and other published and data. Treatability studies using actual samples of waste water are needed to verify the predicted performance data given in Table 7.

14. Batches of partially treated effluents which contain total dissolved solids concentrations in excess of that which can be handled by reverse osmosis will be either solidified directly or evaporated to reduce the total quantity of residue prior to solidification.

Three of the parameters listed in Table 7 have been selected to demonstrate the methodology used to derive the expected performance values presented in Table 7. Subsequent supporting data presented in Tables 8 through 24 and Table B-1 in the Appendix provide a further basis for assessing the performance of the proposed treatment system. These data also show that the preferred combination of physical/chemical treatment technologies is capable of attaining the lowest residual contaminant concentrations achievable using existing proven treatment methods.

It is important to emphasize the operating philosophy for the physical/chemical plant which will enable it to meet treatment objectives other than those presented in Table 7. This is important since the effluent quality requirements for the Facility (liquid or gaseous) have not been established by MOE. Batches of treated effluent which are unsuitable for reuse on site or discharge by evaporation will either be:

- o retreated in the physical/chemical plant,
- o solidified if the residual contaminants are inorganic in nature, or
- o incinerated if the residual contaminants are organic in nature.

Similarly, surface drainage from the central operating area and potentially contaminated drainage from the landfill area will be collected and checked before being released from the Facility. Landfill leachates will also be monitored on a regular basis. If necessary, these miscellaneous flows will be also treated in the physical/chemical plant and either reused on site or discharged to atmosphere by evaporation. This approach will ensure that liquid and gaseous discharges from the site consistently meet the required objectives.

Mercury, copper and phenol have been selected to demonstrate the methodology used to derive the expected effluent concentrations presented in Table 7. Mercury has been selected because it is a volatile metal which is of potential concern from a human health point of view. Copper has been selected because it is expected to be present in varying amounts in a large number of the wastes which are expected to require physical/chemical treatment. Phenol has been selected as an organic contaminant which is also likely to be present in varying amounts and in varying forms in a large number of the wastes expected to require treatment in the physical/chemical plant.

Mercury

Table 8 from Patterson[16] summarizes the lower limit of treatment capability for various technologies which are commonly used for the removal of mercury from wastewaters. Table 9 shows similar data (in this case average achievable concentrations) for a larger number of treatment processes reported by US Environmental Protection Agency[10].

Tables 10 and 11 provide additional data on the effectiveness of sulphide precipitation and coagulation plus filtration for mercury removal over a broad range of concentrations.

Tables 12 and 13 provide additional performance data on the effectiveness of activated carbon and reverse osmosis for mercury removal.

The conclusions which have been drawn from these data plus data from the HIM regional physical/chemical treatment facility in Frankfurt, West Germany have formed the basis for arriving at the expected effluent concentration for mercury which is presented in Table 7. These conclusions are summarized as follows:

- The treatment technologies which have been selected for inclusion in the preliminary design of the physical/chemical treatment facility (i.e. sedimentation, precipitation, coagulation, filtration, activated carbon adsorption and reverse osmosis) are capable of achieving the lowest possible concentrations of mercury reported (i.e. < 1 ug/L).
- Sulphide precipitation is capable of achieving effluent mercury concentrations as low as 10 to 20 ug/L even with very high initial mercury.

TABLE 8

SUMMARY OF TREATMENT TECHNOLOGY FOR MERCURY

Technology	Lower Limit of Treatment Capability Hg (ug/L)
Sulfide Precipitation	10 - 20
Ion Exchange	1 - 5
Alum Coagulation	1 - 10
Iron Coagulation	0.5 - 5
Activated Carbon	
High Initial Hg	20
Moderate Initial Hg	2.0
Low Initial Hg	0.25

ug/L - micrograms per litre

Source: Patterson[16]

TABLE 9

POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR MERCURY

Treatment process	Number of data points Pilot scale	Number of data points Full Scale	removal %	Range of effluent conc., ug/L
Activated Carbon Adsorption				
-granular	6		0	<0.1 - <1.1
-powdered	1		NM	0.6
Chemical Oxidation				
-ozone	1		NM	<1.1
Chemical Precipitation with Sedimentation				
-alum		5	6 - 93	1.7 - 4000
-barium chloride		1	87	0.5
-combined precipitants		4	69 - >97	<0.6 - 980
-lime		5	75 - >96	0.1 - 8.0
-sodium carbonate		2	NM	<1.0 - 11
-sulfide		1	97	200
-unspecified		5	0 - 99	<1.0 - 140
Chemical Precipitation with Filtration				
-lime	3	1	NM	0.5 - 3.3
-sodium sulfide		2	99	<50 - 100
Chemical Reduction		2	NM	<1.0 - <5.0
Coagulation and Flocculation		3	70	0.3 - <1.0
Filtration	8	6	0 - 86	0.1 - 2000
Flotation		8	33 - 88	BDL - 2.0
Oil Separation		2	80	BDL - 2.0
Sedimentation		23	0 - >97	BDL - 84
Ultrafiltration	4	1	11 - 33	0.4 - <2.0
Activated Sludge		24	33 - 94*	ND - 1.6
Lagoons				
-aerated		2	>99	0.1 - 1.6

BDL, below detection limit; ND, not detected; NM, not meaningful; *approximate value.

Source: USEPA[11]

TABLE 10

PRECIPITATION TREATMENT FOR MERCURY

Treatment Chemical	Mercury Concentration (ug/L) Initial	Mercury Concentration (ug/L) Final	Treatment pH	Additional Treatment
Sodium Sulphide	na	< 3	na	vacuum filter
Sodium Sulphide	300-6000	10-125	na	pressure filter
Sodium Sulphide	131 500	20	3.0	"filter"
Magnesium Sulphide	5 000-10 000	10-50	10-11	--
Sodium Sulphide	1 000-50 000	10	na	flocculation + activated carbon
Sulphide	na	< 1000	< 9	--
Sulphide	na	100-300	na	--
Sulphide	na	100 10-20	na	1. none 2. activated carbon
Sulphide	300-6 000	10-125	5.1-8.2	filtration

Source: Patterson[16]

TABLE 11

ALUM AND IRON COAGULATION TREATMENT FOR MERCURY

Coagulant Salt	Dosage (mg/L)	Treatment pH	Mercury (ug/L) Initial	Mercury (ug/L) Final	Additional Treatment
Alum	1000	3	11 300	102	Filtration
Alum	100	na	90	11	--
Alum	100	na	na *	10	--
Alum	21-41	6.7-7.2	5.9-8.0	5.3-7.4	Filtration
Alum	na	7.0	50	26.5	Filtration
Alum	20-30	na	3-8	1.5-6.4	--
Alum	20-30	na	3-16 *	2.3-21.3	--
Iron	34-72	6.9-7.4	4.0-5.0	1.5-2.5	Filtration
Iron	na	8.0	50	3.5	Filtration
Iron	20-30	na	1-17	0.5-6.8	--
Iron	20-30	na	2-17 *	1.2-12.8	--

* Organic mercury.

Source: Patterson[16]

TABLE 12

ACTIVATED CARBON TREATMENT FOR MERCURY

Mercury (ug/L) Initial	Mercury (ug/L) Final	Additional Treatment
na	< 100	Presettling
12-46	< 0.5	--
5.8	0.9	Iron Coagulation
9.3	1.6	Alum Coagulation
na	0.8	--
na	0.2	--
100	10-20	Precipitation
60-87	4.5-6.0	--
0.40-0.81	0.13-0.19	Polymer Added
0.5	0.21	Polymer Added

Source: Patterson[16]

TABLE 13

REVERSE OSMOSIS TREATMENT FOR MERCURY

Case	Mercury ug/L Initial	Mercury ug/L Final	Comments
1	0.55	0.53	full scale; steam electric power generating
2	0.2	0.3	pilot scale; steam electric power generating
3	0.5	< 0.2	pilot scale; steam electric power generating

Source: USEPA[10]

- The results being obtained by regional physical/chemical treatment facilities in Europe (notably HIM in Frankfurt, West Germany) indicate that they can achieve residual mercury concentrations of 10 to 20 ug/L with chemical precipitation (including sulphide precipitation).

- Iron coagulation (with filtration) would appear to be capable of achieving residual mercury concentrations of less than 5 ug/L with initial mercury concentrations of 10 to 20 ug/L but range may exceed 10 ug/L depending on chemical form of mercury (Table 12). Based on these data, a value of 10 ug/L would appear to be achievable on a reasonable consistent basis after several stages of primary and secondary treatment.

- Activated carbon is capable of achieving residual mercury concentrations of less than 1 ug/L when initial mercury concentration is 5 to 10 ug/L but between 1 and 5 ug/L if initial mercury is over 10 ug/L. On this basis, it is assumed that 1 ug/L is achievable on a reasonably consistent basis.

- Reverse osmosis would appear to be capable of achieving some reduction in mercury concentrations even at very low initial values. However, the data presented in Table 13 are somewhat inconclusive in this regard. It is therefore assumed that reverse osmosis in combination with activated carbon should together be capable of achieving residual mercury concentrations of 1 ug/L or less with low initial mercury concentrations.

Copper

Table 14 summarizes achievable effluent copper concentrations after precipitation treatment (Patterson[16]).

Table 15 provides additional data on the removability of copper by a number of different treatment processes (USEPA[10]).

Tables 16 and 17 provide data on the efficiency of copper removal by activated carbon and Tables 18 and 19 provide similar data on the effectiveness of reverse osmosis for removing copper at low concentrations.

The following conclusions have been drawn from these data as a basis for arriving at the expected effluent concentrations for copper given in Table 7.

- The preferred combination of physical/chemical treatment technologies is capable of achieving the lowest effluent copper concentrations reported (i.e. < 0.1 mg/L)
- According to Patterson[16] effluent copper concentrations of less than 0.5 mg/L can generally be achieved by precipitation with proper pH control and proper solids separation.
- This conclusion is supported by the results being obtained by the HIM regional physical/chemical treatment facility in Frankfurt, West Germany. In this case, the copper concentrations reported in some samples have ranged from <0.1 mg/L to 0.4 mg/L.
- An effluent copper level of approximately 0.3 mg/L should be attainable on a reasonable consistent basis after activated carbon adsorption based on the results presented in Tables 16 and 17.
- An effluent copper level of less than 0.1 mg/L should be attainable on a reasonable consistent basis after reverse osmosis provided that the copper concentration in the feed to the reverse osmosis unit is less than or equal to approximately 1.0 mg/L.

TABLE 14
SUMMARY OF EFFLUENT COPPER CONCENTRATIONS AFTER PRECIPITATION TREATMENT

Source and Treatment	Initial Copper Concentration (mg/L)	Final Copper concentration (mg/L)
Metal Processing (Lime)	204-385	0.5
Nonferrous Metal Processing (Lime)	-	0.2-2.3 (prior to sand filtration)
Metal Processing (Lime)	-	1.4-7.8 (prior to sand filtration) 0.0-0.5 (after sand filtration)
Electroplating (caustic, Soda Ash + Hydrazine)	6.0-15.5	0.09-0.25 (soluble) 0.30-0.45 (total)
Machine Plating (Lime _ coagulant)	-	2.2
Metal Finishing (Lime)	-	0-1.2 (avg. 0.19)
Brass Mill (Lime)	10-20	1-2
Plating	-	0.02-0.2
Plating (CN oxidation, Cr reduction, neutralization)	11.4	2.0
Wood Preserving (Lime)	0.25-1.1 (range)	0.1-0.35
Brass Mill (Hydrazine + NaOH)	75-124	0.25-0.85
Silver Plating (CN oxidation, Lime, $FeCl_3$	30 (average)	0.16-0.3 (with sand filtration)

Source: Patterson[16]

TABLE 15

POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR COPPER

Treatment process	Number of data points Pilot scale	Full Scale	removal %	Range of effluent conc., ug/L
Activated Carbon Adsorption				
-granular	16	3	13 - >85	<4.0 - 360
-powdered	4		61 - 96	<5.5 - 29
Chemical Oxidation				
-chlorine		1	14	320
-ozone	2		NM	85 - 590
Chemical Precipitation with Sedimentation				
-alum	1	6	30 - >99	ND - 27 000
-barium chloride		2	>50 - 73	<20 - 30
-combined precipitants		5	43 - 98	9.0 - <320
-lime	4	25	34 - >99	ND - 700
-sodium carbonate		2	4 - 83	48 - 1 300
-sodium hydroxide		5	36 - 98	1.0 - 5 900
-sulfide		1	88	38
-unspecified		19	0 - >99	4.0 - 2.2 x 10^6
Chemical Precipitation with Filtration				
-lime	1	1	99	16 - 100
-sodium sulfide		2	>98	<25 - 30
-unspecified		2	72 - 94	260 - 440
Chemical Reduction		7	21 - 99	BDL - 1 700
Coagulation and Flocculation	2	8	>0 - 99	<10 - 170
Filtration	24	15	0 - >99	<4.0 - 4 500
Flotation		12	9 - 98	5.0 - 660
Naturalization		1	98	30
Oil Separation		3	93 - 99*	BDL - 450
Reverse Osmosis		7	64 - 90	26 - 28 000
Sedimentation	2	38	0 - 99	ND - 1 100
Ultrafiltration	4	2	>44 - 99	BDL - 1 100
Activated Sludge		39	2 - >99*	BDL - 170
Lagoons				
-aerated		8	26 - 94	5.0 - 3 000
-non-aerated		1	NM	18
Trickling Filters		1	NM	42

BDL, below detection limit; ND, not detected; NM, not meaningful; *approximate value.

Source: USEPA[11]

TABLE 16

TREATMENT OF COPPER WASTEWATER

Process	Chemical Addition	pH	Influent Copper (mg/L)	Effluent Copper (mg/L) (carbon column)(1)
Iron Only	43 mg/L $FeSO_4$	6.0	5.0	0.155
Low Lime	260 mg/L Ca $(OH)_2$ 20 mg/L $FeSO_4$	10.0	5.0	0.170
High Lime	600 mg/L Ca $(OH)_2$	11.5	5.0	0.352

Source: Patterson[16]

Notes: (1) Treatment steps were chemical addition, flocculation, settling and sand filtration followed by carbon adsorption.

TABLE 17

TREATABILITY OF COPPER BY ACTIVATED CARBON

Case	Copper (mg/L)			Comments
	Influent	Effluent	% Removal	
1	0.031	0.042	0	laundry waste, full scale
2	1.30	0.36	72	gum & wood chem full scale
3	0.14	<0.050	>64	gold mill; pilot
4	0.012	<0.006	>50	petrol, refining
5	0.027	<0.004	>85	textiles
6	0.110	0.047	57	textiles
7	0.130	0.024	82	textiles
8	0.100	0.087	13	textiles
9	0.025	0.035	0	textiles
10	0.075	0.016	79	textiles
11	0.059	0.042	29	textiles
12	0.120	<0.080	>33	textiles

Source: USEPA[10]

TABLE 18

TREATABILITY OF COPPER BY REVERSE OSMOSIS

Case	Copper (mg/L) Influent	Effluent	% Rejected	Comments
1	4.9	0.050	99	Electroplating
2	170.	28.0	84	Electroplating
3	0.030	0.010	67	Steam, electric
4	0.047	0.010	79	Steam, electric
5	0.014	0.010	29	Steam, electric
6	0.620	0.051	92	Steam, electric
7	0.026	0.009	65	Steam, electric
8	0.180	0.032	82	Steam, electric
9	0.080	0.009	89	Steam, electric
10	0.090	0.032	64	Steam, electric
11	0.480	0.050	90	Textile mills
12	3.1	11.0	0	Textile mills
13	0.090	0.026	71	Textile mills
14	0.480	0.046	90	Textile mills
15A	0.120	0.040	67	Textile mills
B	1.0	0.071	93	Textile mills
16	120.0	0.090	>99	Brass finishing

Source: USEPA[10]

TABLE 19

TREATABILITY OF COPPER BY REVERSE OSMOSIS

Case	Copper (mg/L) Influent	 Effluent	 % Rejected
1	2.1	0.008	99.6
	1.2	0.019	98.4
	1.4	0.027	98.1
2	2.1	0.008	99.6
	1.2	0.019	98.4
	1.4	0.027	98.1
3	0.85	0.027	96.8
	0.62	0.43	93.1
4	5.8	0.3	94.8
	5.8	0.44	92.4
	5.8	0.49	91.6
5	1.3	0.09	93.1
	1.2	0.12	90.0
6	3.3	0.18	94.5
7	6.1	0.37	93.9
	5.6	0.67	88.0
	3.5	0.3	91.4
	3.8	0.44	88.4
8	8.3	0.82	90.1
	7.8	0.98	87.4
	6.9	1.2	82.6

Source: Environment Canada[26]

Phenol

Table 20 summarizes the removability of phenol by a variety of different treatment processes.

Tables 21 and 22 provide additional data on the removability of phenol by activated carbon.

Table 23 provides comparative data on the removability of phenol by a number of different biological treatment processes.

The following conclusions have been drawn from these data as a basis for arriving at the expected effluent concentrations for phenol given in Table 7.

- As indicated in Table 20 significant phenol removal can be achieved by primary and secondary treatment processes such as precipitation, coagulation, filtration and oil separation.

- Activated carbon use is well established and effective for both moderate strengths and dilute phenolic wastes as indicated in Table 21.

- According to the results reported in Table 23, biological treatment methods would not appear to offer any performance advantage over activated carbon from the point of view of achieving the lowest possible effluent levels. However, depending on the carbon usage, biological treatment may be a more efficient (i.e. less costly) process for achieving equivalent levels. For this reason space has been allocated within the physical/chemical building in the event that the addition of a biological treatment unit becomes desirable and practical.

TABLE 20

POLLUTANT REMOVABILITY/TREATABILITY WASTEWATER TREATMENT ALTERNATIVE FOR PHENOL

Treatment process	Number of data points Pilot scale	 Full Scale	removal. %	Range of effluent conc., ug/L
Activated Carbon Adsorption				
-granular	5	2	18 - 90*	BDL. - 49
-powdered		1	93*	5.0
Chemical Precipitation with Sedimentation				
-alum		4	>99	ND - <10
-combined precipitants		3	>33 - 96	<10 - 140
-lime		1	69*	BDL
-sodium carbonate		1	NM	ND
-unspecified		1	NM	74
Chemical Precipitation with Filtration				
-lime		1	NM	13
Coagulation and Flocculation	2	1	91	BDL - 3.0
Filtration	6	7	22 - >99	ND - 34 000
Flotation		9	0 - 80	5 - 2 400
Oil Separation		2	>99	ND - 820
Reverse Osmosis	3		80	0.2 - 0.7
Sedimentation		7	33 - >99	BDL - 670
Solvent Extraction	12	1	3 - >99	77 - 9.6 x 10^6
Ultrafiltration		2	NM	55 - 9 700
Activated Sludge	1	30	8 - >99	ND - 1 400
Lagoons				
-aerated		5	25 - >99	ND - 24
Rotating Biological Contactor	2		56 - 63	1.6 x 10^5 - 1.6 x 10^5
Trickling Filters	1		NM	37

BDL, below detection limit; ND not detected; NM, not meaniful; *approximate value

Source: USEPA[11]

TABLE 21
REMOVAL OF PHENOL BY ACTIVATED CARBON

Source	Phenol (mg/L)		
	Influent	Effluent	% Removed
Chemical manufacture	36.0	0.001	99 +
Dyes	6.0	0.01	99 +
Organic chemicals	0.52	0.05	90 +
	0.12	0.003	97.5 +
	0.315	0.001	99 +
	12.8	0.001	99 +
Inorganic chemicals	5325.0	0.25	99 +
Plastics	9.75	0.013	99 +
	8.5	0.006	99 +
	26.5	0.005	99 +
Explosives	16.6	0.023	99 +
Petroleum refining	44.0	0.001	99 +

Source: Patterson[16]

TABLE 22
REMOVAL OF PHENOL BY ACTIVATED CARBON

Case	Phenol (mg/L)		
	Influent	Effluent	% Removed
1	20.4	>9	>56
2	0.028	0.029	0
3	4.66	0.58	88
4A	77.9	2.32	97
B	2.8	<0.7	>75
C	129	4.26	97
5	0.022	0.010	>55
6	0.023	<0.0115	>50
7	0.032	<0.005	>84
8	0.051	<0.005	>90
9	2.7	0.02	99
10	0.009	<0.0075	>17
11	0.068	0.018	74
12	0.055	0.017	69
13	0.017	0.011	35
14	0.016	0.12	25
15	0.019	<0.002	>89
16	0.013	0.008	38
17	0.017	0.017	0

Source: USEPA[10]

TABLE 23
PERFORMANCE OF BIOLOGICAL SYSTEMS IN THE TREATMENT OF PHENOLIC WASTES

Treatment Process	Source of Industrial Waste	Phenol (mg/L)	
		Influent	Effluent
Biooxidation pond	Refinery wastewater	30	1
Aerated lagoon	Municipal plus herbicide manufacturing waste	0.8-1.65	0.2-0.45
	(Same - Phenoxyacids)	2.15-4.14	1.51-1.73
Stabilization pond	Effluent from aerated lagoon above - phenols	0.2-0.45	0.06-0.13
	(Same - Phenoxyacids)	1.51-1.73	1.10-1.48
Oxidation ditch	Coke oven	990 (ave)	8.5 (ave)
Trickling filter	Oil refinery	30-40	0.5-0.7
	Oil refinery	-	.04
	Oil refinery	9-25	0.6-3.8
	Sourwater and plant sewage	15 (ave)	1.8 (ave)
	Aircraft maintenance wastes	8	0.02
Activated sludge	Coke oven	400-700	10
	Coke oven	6.5	0.008
	Coke oven	9-10	0.9
	Coke oven	890	0.65
	Coke oven	110-200	0-11
	Coke oven with dephenolization	135	7
	Coke oven without dephenolization	1 400	15
	Oil refinery	80	<0.5
	Gas liquor	1 200	12
	Gas liquor	200	0.2
	Stocking manufacture	183-455	0.2-1.3
	Oil refinery	40-80	<1.0
	Fiberglass manufacturing	40-400	0.1-2.6
	Refinery and petrochemical	10-100	<1
Activated sludge plus Dow-Pac Filter	Oil refinery	40-80	0.35
Activated sludge (a)	Coke oven	3 350-3 900	0.2-0.8
Aero accelerator (activated sludge)	Coke oven	150	<1.0
Nocardia Process (b)	Foundary wastes	3 000	30-150
	Explosives	10 000	100

(a) Pilot plant - full scale plant in operation with lower loadings consistently produces 0.1 mg/L or 99.9% removal.

(b) Activated sludge with specially adapted organism culture for phenol removal.

Source: Patterson[16]

TABLE 24

REMOVAL OF PHENOL BY REVERSE OSMOSIS

Case	Phenol (mg/L) Influent	Effluent	% Removal
1	0.006	0.016	0
2	0.019	0.018	5
3	0.064	0.012	81
4	0.004	<0.001	>75
5	0.006	0.012	0
6	0.019	0.02	0

Source: USEPA[10]

- Activated carbon would appear to be capable of achieving effluent phenol concentrations of 0.02 mg/L or less on a reasonably consistent basis particularly in cases where the influent phenol concentration (to the final stage of activated carbon treatment) is less than approximately 10 mg/L.

- The results shown in Table 24 for reverse osmosis are quite variable and therefore somewhat inconclusive. However, Shuckrow[24] and others (Chian[27], Fang [28], and Dryden[29]) have reported that the performance of reverse osmosis is heavily dependent on membrane material with 60 - 80% separation of phenols being reported with cross linked polyethylenimine (C-PEI) membranes. For the purposes of arriving at the estimated effluent concentration for phenol given in Table 7 it has been conservatively assumed that the reverse osmosis units would not contribute significantly to the overall phenol removal efficiency of the system.

4.5.4 Removal of Organics

The US Environmental Protection Agency has collected and summarized data and information from the literature relating to the treatability of various organic and inorganic contaminants of concern in industrial wastes, municipal wastes, contaminated ground and surface waters and contaminated leachates (Shuckrow[24], US Environmental Protection Agency[10]).

Shuckrow[24] has summarized treatability data for over 500 organic and inorganic contaminants. These have been grouped according to their chemical classification.

Table B-1 in Appendix B presents treatability data for a selected number of these parameters. A majority of the contaminants included in Table B-1 have been selected because they are included in the US Environmental Protection Agency list of priority pollutants. A few, (such as ethylene glycol and glycerine) have been included because they have been identified in OWMC's inorganic waste profile data. These data provide a useful basis for further demonstrating the capabilities of the various components of the proposed physical/chemical treatment system for treating a wide range of contaminants which could be present in the inorganic wastes requiring treatment in the physical/chemical plant.

The contaminant classes presented in Table B-1 are generally listed in descending order of frequency of occurrence in industrial effluents, contaminated surface water, groundwater and leachates. The results reported by US Environmental Protection Agency[30] on the frequency of occurrence of various organics in industrial effluents and, the data compiled by Shuckrow[24] on the presence of various classes of organics in surface drainages, groundwater and leachates from active and abandoned hazardous waste disposal sites in the United States are reasonably consistent in this regard. Halogenated aliphatics, aromatics and phenols tend to occur most frequently whereas amines and alcohols tend to occur least frequently.

Unfortunately, the treatability data presented in Table B-1 do not encompass all possible contaminants over a wide range of concentrations for all possible unit treatment processes. This type of data is simply not available. However, the available data do provide an indication of the capabilities of a number of the selected physical/chemical treatment processes for removing major classes of organic compounds from dilute aqueous waste streams. The specific criteria which will be used as a basis for determining whether a particular aqueous/organic waste is suitable for physical/chemical treatment or, whether incineration is a more appropriate method of treatment are summarized in the notes accompanying Table 1 (p. 8).

The following conclusions can be drawn from the data presented in Table B-1.

Halogenated Aliphatics. The proposed system is expected to be capable of achieving effective removals of halogenated aliphatics at various stages of the treatment process. For example, the concentrations of some of the more volatile halogenated organics will be reduced due to volatilization in the air flotation unit and the reaction tanks. These contaminants will be recaptured by adsorption onto the activated carbon stage of the ventilation air scrubbing system. According to the US Environmental Protection Agency[30], chloroform and methylene chloride are two priority pollutants which have been observed with highest frequency in industrial effluents. Both of these organics have half lives (the time required for 50% reduction to occur by volatilization in a stirred reactor) of approximately 20 minutes.

Cohen[31] and USEPA[30] have reported removal rates of 50% or more for various halogenated aliphatics by chemical coagulation followed by filtration.

Halogenated aliphatics in the concentration range of 0.001 to 1000 mg/L were reported to be readily absorbed by activated carbon with removal rates of 75 to 100% frequently reported (Shuckrow[24]).

Reverse osmosis has also been shown to be capable of achieving efficient separation of higher molecular weight organic compounds particularly where cross-linked polyethylenime (C-PEI) membrane materials are used. On this basis it is reasonable to assume that reverse osmosis will affect additional removals of halogenated aliphatics which escape removal by multi-stage activated carbon adsorption. (Shuckrow[24]).

Alternative unit processes such as biological treatment are not expected to improve the overall performance of the physical/chemical treatment system for removing halogenated aliphatics in general because many of these compounds tend to be toxic and/or biorefractory.

Aromatics. The proposed treatment system is also expected to be highly effective for the removal of a wide variety of aromatic compounds.

Although some volatilization of these compounds can be expected to occur during the secondary physical/chemical treatment processes the effect of volatilization on the overall removal efficiency of the system will be less for aromatics than for many of the volatile halogenated aliphatics due to their lower volatility. The volatilization half life for benzene and toluene for example is approximately 5 hours compared to 20 minutes previously indicated (p. 204) for methylene chloride.

Shuckrow[24] reports that, at concentrations of 0.1 to 6 000 ppm, greater than 50% removal is achievable with carbon adsorption for all aromatics with greater than 90% removal reported for many.

Although only limited data are available for removal of aromatic compounds by reverse osmosis, removal rates of 80 to 90% have been reported with C-PEI membranes (Chian[27]).

Alternative processes such as biological treatment would not be expected to improve the overall performance of the physical/chemical treatment system for removing most aromatics because a number of the organic compounds in this group are toxic and/or biorefractory.

Phenols. As outlined in Section 4.3.3 p. 197, effective phenol removal rates are expected to occur at various stages of the physical/chemical treatment process with maximum removals being achieved by activated carbon treatment. Carbon adsorption is generally considered to be an effective and efficient process for reduction of phenolic compounds (Shuckrow[24]). Hager[32] reports results from five full scale carbon adsorption systems treating phenolic wastes in which 83 - 99% total organic carbon (TOC) removals were achieved at TOC concentrations of 80 to 1200 mg/L. Additional phenol removals are expected to be obtained by reverse osmosis treatment using C-PEI membranes. Chian[27], Fang[28] and Dryden[29] have reported achieving 60 - 80% phenol removals with these types of membranes.

Pesticides. Due to their relatively low solubility in water pesticides will tend to be removed to some extent by secondary physical separation processes such as coagulation and filtration. As indicated in Table B-1, removal rates for pesticides ranged from 35 to 98% by coagulation and filtration. Organic pesticides are removed effectively by carbon adsorption with reductions exceeding 75% in virtually all cases with reductions of 99% or more in many cases. Reverse osmosis is also reported to be capable of achieving greater than 99% removal of pesticides (Chian[27]).

Pesticides are generally reported to be either non-biodegradable or only slightly biodegradable therefore alternative processes such as biological treatment would not be expected to improve the performance of the system for removing low concentrations of pesticides from inorganic wastes.

Polynuclear Aromatics. Dryden[29] has reported that many polynuclear aromatics are removable by coagulation and gravity separation. This is supported by the US Environmental Protection Agency[10] which reports removal rates for naphthalene of up to 98% by sedimentation with chemical addition.

According to Shuckrow[24] and the data shown in Table B-1 adsorption of polynuclear aromatics is generally high with activated carbon. The data given in Table B-1 indicate 70 to 80% removals for various compounds of this class.

The biodegradability of polycyclic aromatics tends to be quite variable depending on the compound type and its concentrations. Concentrations above 500 mg/L tend to be either inhibitory or toxic. At lower concentrations removal rates can vary from less than 50% to 95%. As such, biological treatment would not be expected to improve the overall performance of the system for removing polycyclic aromatics.

Aliphatics. Adsorption of aliphatics with activated carbon tends to be quite variable with the higher molecular weight, less soluble polar organics tending to be most easily adsorbed. As indicated in Table B-1, removal rates for most aliphatics with activated carbon are less than 50%. Compounds such as glycols are not readily adsorbed on activated carbon due to their high solubility in water. Reverse osmosis has been shown to be capable of somewhat higher removal rates for aliphatics in some cases up to 100% depending upon the membrane type and the compound being removed (Table B-1).

The available treatability data would suggest that biological treatment may be capable of improving the efficiency of removing certain aliphatics since more than one stage of activated carbon treatment will likely be required to obtain equivalent removal rates. For the reasons outlined previously in Section 3.7.3, p. 109, provision has been made in the design of the physical/chemical plant to add a dedicated biological treatment step to the process train if required after start-up. In the short term, it would be possible to use one of the reaction tanks for biological treatment in a sequencing batch configuration.

Phthalates. Phthalates are used as plasticizers in many synthetic materials therefore they are present in varying amounts in a very large number of industrial effluents (US Environmental Protection Agency[30]). Bis 2-ethylhexylphthalate is one of the most commonly occurring compounds of this class. Significant reductions of these compounds are expected to occur as a result of the secondary coagulation and filtration processes. As indicated in Table B-1 removal rates by these processes can be as high as 80 to 90%.

Despite their apparent wide spread occurrences, data on the treatment of phthalate compounds by activated carbon is limited (Shuckrow[24]). The data which are presented in Table B-1 and elsewhere (US Environmental

Protection Agency[10]) would suggest that phthalates can be effectively removed (up to 98%) by both activated carbon and reverse osmosis.

Biological treatment has also been shown to be effective in removing phthalate compounds with removal rates ranging from 50 to 100% (Shuckrow[24]) Therefore depending on the actual frequency of occurrence and concentrations of phthalates in the feed to the physical/chemical plant, it might be advantageous to add a biological unit to reduce the organic loading to the activated carbon units thereby increasing the efficiency of the treatment process.

Amines. Very little treatability data are available for amines. However, from Table B-1 it would seem that some compounds in this group e.g. benzidine and di-n-propylamine are treatable by activated carbon adsorption. Since there also appears to be significant variability in the biodegradability of these compounds, it is unlikely that biological treatment will improve the overall system performance. Batches of inorganic waste which contain high concentrations of amine compounds which are not amenable to treatment by physical/chemical methods will be incinerated.

Alcohols. The treatability of alcohols by activated carbon varies considerably according to the molecular weight and solubility of the particular compound. Higher molecular weight alcohols tend to be more readily adsorbed on activated carbon. Reverse osmosis is also more effective on high molecular weight alcohols although up to 100% removals of ethanol have been noted by Chian[27]. On the other hand a majority of alcohols tend to be biodegradable with removal rates of up to 100% depending on the compound and its initial concentration.

To maximize the effectiveness of the treatment process for these types of compounds the system has been designed to provide up to three separate stages of activated carbon treatment followed by two stages of reverse osmosis treatment. In some cases, it may be necessary to incinerate batches of aqueous waste which contain high concentrations of alcohols to avoid allowing them to pass through the physical/chemical treatment system untreated.

If these types of compounds are encountered in high concentrations on a regular basis, it may be appropriate to consider adding a biological treatment step to the process train in order to improve the cost effectiveness of the overall treatment process. As indicated previously provision has been made for this in the layout of the physical/chemical plant.

4.5.5 Evaporator Emissions

Table 25 presents predictive data on the expected quality of the evaporator emissions for a number of organic and inorganic contaminants of potential concern to human health and the environment.

The selection of the twenty contaminants presented in Table 25 was based on the following criteria:

- Together these contaminants represent a wide range of compound classes which are of potential concern to human health and the environment.

- All are known to be either toxic or to produce carcinogenic effects.

- Any of these contaminants could be present in measureable quantities in the inorganic or aqueous/organic wastes which require treatment in the physical/chemical treatment plant.

- Data are available on the range of contaminant concentrations which are likely to be present in untreated industrial wastes and on the treatability of these compounds by physical/chemical methods.

The derivation of the data presented in each column in Table 25 is outlined in Appendix C.

TABLE 25

ESTIMATED EVAPORATOR EMISSIONS

Column	1	2	3	4	5	6
Contaminant	Expected Conc. In Influent to P/C Plant		Expected Avg Quantity of Waste Containing Contaminant (t/a)	Expected Conc. After Primary & Secondary Treatment (mg/L)	Expected Conc. After Polishing with Act.C & RO (mg/L)	Average Contaminant Discharge Rate From Evaporator (g/sec)
	Average (mg/L)	Max. (mg/L)				
Pesticides						
o Aldrin	0.006	0.010	900	0.006	6.0×10^{-5}	1.78×10^{-9}
o Lindane	0.004	0.020	900	0.004	6.0×10^{-6}	1.78×10^{-10}
PCBs						
o Aroclor 1242	0.05	1.4	1000	1.5×10^{-3}	1.5×10^{-5}	4.95×10^{-10}
Halogenated Aliphatics and Methanes						
o Methylene Chloride	50.0	3400	36 000	5	0.5	5.94×10^{-4}
o Carbon Tetrachloride	1.0	30	9 000	0.05	0.013	3.86×10^{-6}
o Trichlorethylene	5.0	1300	9 000	0.5	0.025	7.42×10^{-6}
o Chloroform	1.0	280	45 000	0.1	0.006	8.91×10^{-6}
Halogenated Ethers						
o Bis (2-Chloroethyl) Ether	0.2	1.7	9 000	0.2	0.1	2.97×10^{-5}
Aromatics & Chlorinated Aromatics						
o Benzene	5.0	46	27 000	0.25	0.015	1.33×10^{-5}
o Hexachlorobenzene	0.1	5	7 500	0.01	5.0×10^{-4}	1.24×10^{-7}

TABLE 25 (Cont'd)

ESTIMATED EVAPORATOR EMISSIONS

Column	1	2	3	4	5	6
	Expected Conc. In Influent to P/C Plant					
Contaminant	Average (mg/L)	Max. (mg/L)	Expected Avg Quantity of Waste Containing Contaminant (t/a)	Expected Conc. After Primary & Secondary Treatment (mg/L)	Expected Conc. After Polishing with Act.C & RO (mg/L)	Average Contaminant Discharge Rate From Evaporator (g/sec)
Polycyclic Aromatics						
o Acenaphthene	1.0	55	4500	0.5	0.012	1.78×10^{-6}
o Benzo (k) Fluoranthene	0.1	3.9	1800	0.01	0.001	5.94×10^{-8}
Phthalate Esters						
o Butyl Benzyl Phthalate	0.6	10	13 500	0.03	6.0×10^{-4}	2.67×10^{-7}
Nitrosamines & Miscellaneous Organics						
o Acrylonitrile	10.0	46	4500	10.0	*2.0	2.97×10^{-4}
Phenolics						
o 2,4,6 - Trichlorophenol	1.0	5.9	9000	0.2	0.002	5.94×10^{-7}
o 2 - Chlorophenol						
- Annual Avg	1.0	36	4500	1.0	0.02	2.97×10^{-6}
- 2 wk Avg	3.0		4500	3.0	0.06	8.91×10^{-6}

TABLE 25 (Cont'd)

ESTIMATED EVAPORATOR EMISSIONS

Column	1	2	3	4	5	6
	Expected Conc. In Influent to P/C Plant		Expected Avg Quantity of Waste Containing Contaminant (t/a)	Expected Conc. After Primary & Secondary Treatment (mg/L)	Expected Conc. After Polishing with Act.C & RO (mg/L)	Average Contaminant Discharge Rate From Evaporator (g/sec)
Contaminant	Average (mg/L)	Max. (mg/L)				
Inorganics						
o Arsenic	0.6	310	64 000	0.1	0.05	2.64×10^{-9}
o Beryllium	0.1	0.9	73 000	0.01	0.01	6.03×10^{-10}
o Chromium	20.0	1000	73 000	1.0	0.05	3.02×10^{-9}
o Mercury - Annual Avg	2.0	120	54 000	0.01	0.001	4.46×10^{-11}
- 2 wk Avg	6.0	-	54 000	0.01	0.001	4.46×10^{-11}

The data presented in Table 25 contains emission data that is being used to confirm the compliance of emissions with Ontario Regulations and determine health risks. This work is ongoing and being undertaken by Ontario Research Foundation and Environ Corporation respectively, and will be available prior to the formal environmental assessment submission.

The preliminary conclusions which have been drawn from these assessments are as follows:

- The estimated evaporator emission values given in Table 25 are many orders of magnitude lower than the current MOE standards, tentative standards, guidelines and provisional guidelines.
- In addition, projected ambient air concentrations for the specific contaminants considered are lower than levels corresponding to a one-in-one-million cancer risk for carcinogens or acceptable daily intake values (ADIs) for non-carcinogens.
- The differences between the expected and maximum acceptable concentrations are sufficient to accommodate considerable inaccuracy in the values of influent concentration, waste quantity and treatment removal efficiency which have been used as a basis for calculating the evaporator emission rates for each contaminant.
- A conservative approach has been taken in calculating the expected emission rates by assuming that all organic contaminants in the evaporator feed will volatilize to the vapour phase and be discharged with the steam plume.

The results obatined to date from the work being conducted by Environ Corporation and Ontario Research Foundation indicate that OWMC's physical/chemical treatment plant will treat wastes in a highly effective manner which will thereby minimize risk to human health and impact on the environment.

4.6. SUMMARY AND CONCLUSIONS

Previous sections have summarized the performance potential of the physical/chemical treatment system. To ensure that this performance potential can be achieved on a consistent basis during actual plant operation, a number of key features have been incorporated into the design and operating philosophy of the physical/chemical plant. These features, which have been outlined previously in various sections of this report and are summarized as follows:

- Best available treatment technology has been included in the design of the physical/chemical treatment system.
- Provision has been made for treatability testing to be carried out on actual waste samples prior to full scale treatment.
- Maximum processing flexibility has been incorporated in the system design to enable the optimum treatment processing sequences to be selected for each batch of waste being treated.
- Space has been allocated for additional physical, chemical or biological treatment processes as required to improve the efficiency of the treatment process and take advantage of improvements in treatment technologies.
- Provision has been made for carrying out quality control checks during and after treatment to verify that the system is performing as planned.
- Provision has been made for retreating batches of waste which fail to meet the treatment objective.
- Batches of treated effluent which are unsuitable for reuse or discharge by evaporation will either be incinerated, if the residual contaminants are organic in nature, or solidified, if the residual contaminants are inorganic in nature.

- Similarly, treated residues which are not suitable for direct solidification due to their organic content will be subjected to incineration for the destruction of organics.

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GLOSSARY OF TERMS

The following are definitions of special terms used in this report presented in alphabetical order.

BASIS OF DESIGN: The criteria on which the design of the treatment process or system is based, including incoming waste quantity and characteristics, treatment objectives, facility capacity, mode of operation, process reliability etc.

BIOLOGICAL TREATMENT PROCESSES: Biological treatment processes refer to any processes which utilize living microorganisms to achieve treatment of a waste stream. Activated sludge systems and aerated lagoons are two examples of biological treatment systems.

BLOWDOWN: That portion of the water or solution in the evaporator (evaporator blowdown) which is discharged in order to maintain the concentration of dissolved solids at predetermined limits.

CATALYST: A substance whose presence increases the rate of chemical reaction.

CHEMICAL TREATMENT PROCESSES: Chemical treatment processes generally refer to processes which bring about a chemical transformation of one or more components of a waste stream as the primary means of either removing a particular component or reducing its toxicity. Chemical oxidation and precipitation are two examples of chemical treatment processes.

CONTAMINANT: Any solid or liquid chemical element or component individually or in combination which may:-

- impair the quality of the environment or the public therein for any use that can be made of it,
- cause injury or damage to property or plant or animal life,
- cause harm or material discomfort to any person,
- adversely affect the health or impair the safety of any person, or
- render any property or plant or animal life unfit for use by man.

DETOXIFICATION: Treatment of materials to remove, immobilize or destroy toxic components.

EFFLUENT: Liquid streams resulting from complete physical/chemical treatment of wastes, unless otherwise qualified. Synonymous with Treated Effluent.

EFFLUENT POLISHING: "Effluent polishing" is defined as the final stage(s) of physical/chemical treatment. The effluent polishing steps are designed to remove residual concentrations of suspended solids, organic contaminants and inorganic contaminants particularly toxic heavy metals. Activated carbon adsorption and reverse osmosis are examples of effluent polishing processes.

LEACHATE: The liquid from a landfill resulting from water percolating through and picking up soluble contaminants en route. The percolating water is the leachant and the ability of the material to leach is called its leachability.

PHYSICAL TREATMENT PROCESSES: Physical treatment processes generally refer to processes which are designed to separate and concentrate the various components of a waste stream without chemically altering the form of these components. Filtration and ion exchange are two examples of physical treatment processes.

PHYSICAL/CHEMICAL TREATMENT PROCESSES: Physical/chemical treatment processes commonly refer to processes whose main operating principles involve either physical treatment, chemical treatment or some combination of both physical and chemical treatment.

POLLUTANT: Synonymous with contaminant.

POLYMER: A high molecular weight organic compound which acts as a bridge to reduce the natural repulsive forces which exist between charged colloidal particles (solids or liquids) in suspension. Synonymous with polyelectrolyte.

PRIMARY TREATMENT: For the purposes of the OWMC Physical/Chemical Treatment Facility, "primary treatment" is defined as a first stage of physical chemical treatment designed to prepare certain wastes for subsequent treatment. Phase separation, blending and dissolutions are examples of primary treatment processes.

RESIDUE: Solids, semi-solid or liquid materials remaining after incineration or organic wastes and physical/chemical treatment of inorganic wastes.

SECONDARY TREATMENT: For the purpose of the OWMC Physical/Chemical Treatment Facility, the term "secondary treatment" generally refers to those unit operations which serve to prepare inorganic and mixed organic/inorganic wastes for subsequent final effluent polishing. The secondary level physical/chemical treatment processes are therefore aimed at reducing contaminant levels to the maximum extent possible to reduce the contaminant loadings in preparation for final effluent polishing for the process waste treatment system. Chemical oxidation, precipitation, coagulation and sludge dewatering are examples of secondary treatment processes.

SOLIDIFICATION: The process by which chemically reactive formulations and components in the waste form stable solids which will revert to the original liquid or semi-liquid state under conditions anticipated in the landfill.

SYSTEM: The assembly of equipment, piping, instruments, electrics, foundations and structures into an installation in which process treatment is executed.

TREATMENT: When used in connection with hazardous waste, means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous wastes so as to neutralize such waste or so as to render such waste less or non-hazardous, safer for transport, amenable for recovery, amenable for storage, or reduced in volume.

APPENDIX A

TECHNOLOGY EVALUATION

APPENDIX A

This appendix should be read in conjunction with Section 3.3, "Criteria for Technology Selection" which defines the criteria, their weightings and how these criteria have been applied in the evaluations of alternative treatment technologies.

TABLE A-1

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE OXIDATION PROCESSES

PROCESS	TOTAL SCORE
Sodium Hypochlorite	305
Hydrogen Peroxide	282
Calcium Hypochlorite	272
Potassium Permanganate	254
Chlorine	248
Air/Sulphur Dioxide	232
Ozone	223
Electrolysis	159

Refer to pages A-3 to A-10 for comparison of oxidation processes.

TABLE A-1
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	CHLORINE Cl_2	CALCIUM HYPOCHLORITE $Ca(OCl)_2$	SODIUM HYPOCHLORITE NaOCl
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	LESS EFFECTIVE ON CN WASTES CONTAINING SULPHATE. PRESENCE OF Cl- REQUIRED TO IMPROVE PERFORMANCE. NOT EFFECTIVE ON Ni, Cu AND Fe COMPLEXES. (2) (20)	YES, WILL OXIDIZE CN, NH_3, PHENOL, S^{-2}; MAY NOT BE EFFECTIVE ON Fe COMPLEXES. (3) (30)	YES, EXCEPT FOR FERRICYANIDE (3) (30)	YES, EXCEPT FOR FERRICYANIDE (3) (30)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	VERY LONG REACTION TIMES NORMALLY REQUIRED (I.E. DAYS). LESS EFFECTIVE ON STREAMS CONTAINING SULPHATE. (1) (2)	- 2.7 KG Cl_2/KG CN - LIME OR CAUSTIC REQUIRED FOR pH CONTROL. (3) (6)	- 2.7 KG $Ca(OCl)_2$/KG CN - LIME OR CAUSTIC REQUIRED FOR pH CONTROL. SOURCE IN POWDERED FORM OVERALL REAGENT IS 4.2 KG CA $(OCl)_2$ /KG CN (3) (6)	- 2.7 KG NaOCl/KG CN - DUE TO LOW SOLN STRENGTH OF COMMERCIAL GRADE PRODUCT OVERALL REAGENT REQUIREMENT IS RELATIVELY HIGH I.E. 27 KG SOLN/KG CN (2) (4)
RESIDUE CHARACTERISTICS	2	CO_2, N_2, NH_3, SOME CNO LEFT IN SOLN AT LOWER CYANIDE CONCENTRATIONS. MAY REQUIRE CHLORINATION TO COMPLETE TREATMENT. (1) (2)	- CO_2, N_2, Cl_2 (EXCESS) - MAY PRODUCE CHLORINATED HYDROCARBONS - EXCESS Cl REMAINS IN SOLN. (2) (4)	- CO_2, N_2 - CALCIUM MAY CAUSE DOWNSTREAM SCALING. (2) (4)	- CO_2, N_2 - REACTION BYPRODUCTS ARE SOLUBLE. THEREFORE DOWNSTREAM SCALING IS NOT LIKELY TO BE A PROBLEM. (3) (6)
EXTENT USED ELSEWHERE	6	NOT WIDELY USED IN WASTE TREATMENT APPLICATIONS. (3) (8)	COMMONLY USED FOR CN DESTRUCTION. (4) (24)	COMMONLY USED FOR CN DESTRUCTION. (4) (24)	COMMONLY USED FOR CN DESTRUCTION. MOST OFTEN USED IN EUROPEAN PHYS/CHEM TREATMENT FACILITIES. (5) (30)
SAFETY					
OCCUPATIONAL RISK	10	POTENTIALLY HAZARDOUS BY-PRODUCT GASES ARE EMITTED FROM ELECTRODES INCL. H_2 AND Cl_2. (2) (20)	HIGH POTENTIAL HAZARD DUE TO RISK OF HANDLING Cl_2 IN PRESSURIZED CYLINDERS. (1) (10)	MODERATE TO LOW. SOME RISK DURING HANDLING DUE TO DUSTING. (3) (30)	LOW. SHIPPED AND FED AS LIQUID THEREFORE CAN BE HANDLED IN TOTALLY ENCLOSED SYSTEM. (4) (40)
ENVIRONMENTAL RISK	10	NORMALLY LOW SINCE CONCENTRATIONS OF BY-PRODUCT GASES ARE LOW. (3) (30)	HIGH DUE TO POTENTIAL FOR RELEASE OF Cl_2 GAS. (1) (10)	LOW (3) (30)	LOW (3) (30)

TABLE A-1 (CONT'D)
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	CHLORINE Cl_2	CALCIUM HYPOCHLORITE $Ca(OCl)_2$	SODIUM HYPOCHLORITE NaOCl
FLEXIBILITY					
WASTE QUANTITIES	7	MORE SENSITIVE TO VOLUME VARIATIONS THAN CHEMICAL METHODS DUE TO LONG RANGE (1) (5)	VARIATIONS EASILY ACCOMMODATED DUE TO RELATIVELY SHORT REACTION TIMES. (3) 15)	SAME AS Cl_2 (3) (15)	SAME AS Cl_2 (3) (15)
WASTE CHARACTERISTICS	7	BETTER SUITED TO HIGH CONCENTRATIONS OF CN. LESS PRACTICAL FOR LOWER CONCENTRATIONS. NOT WELL SUITED TO DISSOLVED ORGANICS. (2) (10)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL			
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	ELECTRODES ARE POTENTIALLY HIGH MAINTENANCE ITEM DUE TO SCALING OR OXIDATION. (1) (1)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)
SPARE PARTS	2	SPARE ELECTRODES REQUIRED IN ADDITION TO USUAL SPARE PARTS INVENTORY. (2) (2)	NO UNUSUAL SPARE PARTS REQUIRED. (3) (6)	SAME AS Cl_2 (3) (6)	SAME AS Cl_2 (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	PARTS READILY AVAILABLE BUT ELECTRODES WOULD HAVE TO BE STOCKED DUE TO POTENTIAL LONG DELIVERY (2) (6)	Cl_2 IS READILY AVAILABLE (3) (9)	$Ca(OCl)_2$ IS READILY AVAILABLE. (3) (9)	NaOCl IS READILY AVAILABLE. (3) (9)
ROBUSTNESS OR EQUIPMENT	1	LESS ROBUST THAN CHEMICAL METHODS DUE TO POSSIBILITY OF ELECTRODE FAILURE DURING PROCESS. (1) (1)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	MORE VULNERABLE TO PROCESS BREAKDOWNS THAN CHEMICAL METHODS DUE TO POSSIBILITY OF ELECTRODE FAILURE. (2) (6)	SAME AS OTHER CHEMICAL METHODS. (3) (24)	SAME AS OTHER CHEMICAL METHODS. (3) (24)	SAME AS OTHER CHEMICAL METHODS. (3) (24)

TABLE A-1 (CONT'D)
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	CHLORINE Cl_2	CALCIUM HYPLOCHLORITE $Ca(OCl)_2$	SODIUM HYPLOCHLORITE NaOCl
OPERATIONS					
COMPLEXITY	6	EQUIPMENT IS GENERALLY MORE COMPLEX THAN THAT REQUIRED FOR CHEMICAL OXIDATION. (1) (6)	EQUIPMENT IS RELATIVELY SIMPLE. ALTHOUGH CHLORINE FEEDING SYSTEM IS SPECIALIZED. (3) (18)	EQUIPMENT IS RELATIVELY SIMPLE. PROVISION MUST BE MADE FOR HANDLING GRANULAR $Ca(OCl)_2$. (3) (18)	EQUIPMENT IS VERY SIMPLE SINCE REAGENT IS DELIVERED AND FED AS LIQUID. (4) (24)
DEGREE OF AUTOMATION	3	DISCHARGE QUALITY CAN BE CONTROLLED WITHIN LIMITS BY VARYING REACTION TIME. HOWEVER, SOME CN COMPLEXES ARE NOT AMENABLE TO TREATMENT BY THIS METHOD REGARDLESS OF TIME ALLOWED. (3) (9)	CAN BE AUTOMATED BUT REQUIRES OPERATOR ATTENTION. OPERATOR HAS CONTROL OF DISCHARGE QUALITY BY VARYING REACTION TIME. (3) (9)	SAME AS Cl_2. (3) (9)	SAME AS Cl_2. (3) (9)
START UP ASSISTANCE	1	START-UP AND TRAINING ASSISTANCE READILY AVAILABLE. MORE TRAINING LIKELY REQUIRED DUE TO HIGHER COMPLEXITY OF EQUIPMENT. (2) (2)	READILY AVAILABLE. TRAINING IS IMPORTANT DUE TO HAZARD ASSOCIATED WITH POTENTIAL FOR RELEASE OF Cl_2 GAS. (2) (2)	READILY AVAILABLE. TRAINING IS STRAIGHTFORWARD. (4) (4)	READILY AVAILABLE. TRAINING IS STRAIGHTFORWARD. (4) (4)
COMMERCIAL & ECONOMIC					
RESTRICTION ON USE	1	MAY BE APPLICABLE DEPENDING ON EQUIPMENT SELECTED. NOT APPLICABLE IN MOST CASES. (4) (4)	N/A (5) (5)	N/A (5) (5)	N/A (5) (5)
COST	7	EQUIPMENT COSTS ARE GENERALLY HIGHER COMPARED TO CHEMICAL OXIDATION METHODS DUE TO HIGHER COMPLEXITY OF ELECTROLYSIS EQUIPMENT. OPERATING COSTS DEPEND ON WASTE CHARACTERISTICS HOWEVER, DILUTE WASTES ARE NORMALLY MORE COSTLY TO TREAT. (2) (14)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. Cl_2 IS THE LEAST EXPENSIVE OF THE CONVENTIONAL OXIDANTS. (4) (28)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. $Ca(OCl)_2$ IS APPROXIMATELY THREE TIMES THE COST OF Cl_2. (2) (14)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. NaOCl IS APPROXIMATELY TWICE AS EXPENSIVE AS Cl_2. (3) (21)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			

TABLE A-1 (CONT'D)
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	CHLORINE Cl_2	CALCIUM HYPOCHLORITE $Ca(OCl)_2$	SODIUM HYPOCHLORITE NaOCl
COMMERCIAL AND ECONOMIC (con't)					
DELIVERY	1	POTENTIALLY LONG DUE TO COMPLEXITY OF EQUIPMENT. (1) (1)	REASONABLE DUE TO SIMPLICITY OF EQUIPMENT. (5) (5)	SAME AS Cl_2. (5) (5)	SAME AS Cl_2. (5) (5)
CANADIAN BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUPPLY AND FABRICATION OF EQUIPMENT	2	IN SOME CASES, EQUIPMENT WILL BE FABRICATED IN U.S. (2) (4)	AVAILABLE IN ONTARIO. (5) (10)	AVAILABLE IN CANADA. (3) (6)	AVAILABLE IN ONTARIO. (5) (10)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
TOTAL SCORES		159	248	272	305

TABLE A-1 (CON'T)

COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	OZONE O_3	POTASSIUM PERMANGANATE $KMnO_4$	HYDROGEN PEROXIDE H_2O_2	AIR/SULPHUR DIOXIDE AIR/SO_2
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	YES, INCLUDING FERRICYANIDE WHEN UV IS USED. (5) (50)	- GENERALLY EFFECTIVE BUT NO DATA ON FERRICYANIDE OXIDATION - HYDROLYSIS REQUIRED TO BREAK DOWN CNO (2) (20)	YES, EXCEPT HYDROLYSIS REQUIRED TO BREAK DOWN CNO. EFFECTIVE ON Fe COMPLEXES. (2) (20)	- YES, FERRICYANIDE REMOVED BY PRECIPITATION. - SCN IS NOT OXIDIZED (3) (30)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	- 1.8 KG O_3/KG CN - EFFICIENCY OF OZONE GENERATION IS LOW. (2) (4)	- 6 KG $KMnO_4$/KG CN - LIME OR CAUSTIC NOT REQUIRED FOR pH CONTROL. (2) (4)	2.6 KG H_2O_2 AS 50% SOLN/KG CN (3) (6)	- 2.5 KG SO_2/KG CN - 1.2 KG AIR/KG CN - COPPER REQ'D AS CATALYST - LIME OR CAUSTIC REQ'D FOR pH CONTROL. (2) (4)
RESIDUE CHARACTERISTICS	2	- CO_2, N_2, O_3 - NO DISSOLVED SOLIDS ADDED TO WASTE. (5) (10)	MnO_2 MUST BE REMOVED FROM TREATED WASTE. (2) (4)	- CO_2, NH_3 - NO DISSOLVED SOLIDS ADDED TO WASTE. (5) (10)	- EXCESS AIR/SO_2 - SULPHATE IS BY-PRODUCT - COPPER CATALYST MUST BE REMOVED (2) (4)
EXTENT USED ELSEWHERE	6	NOT WIDELY USED FOR CN DESTRUCTION. (3) (18)	NOT WIDELY USED FOR CN DESTRUCTION. (3) (18)	NOT WIDELY USED FOR CN DESTRUCTION. (3) (18)	RELATIVELY NEW PROCESS. NOT IN WIDE SCALE APPLICATION. (2) (12)
SAFETY					
OCCUPATIONAL RISK	10	- MODERATE - O_3 IS QUITE TOXIC BUT PRESENT AT RELATIVELY LOW CONCENTRATIONS (3) (30)	- MODERATE TO LOW - POSSIBLE RISK DUE TO DUSTING DURING HANDLING (3) (30)	LOW - SHIPPED AND FED AS LIQUID THEREFORE CAN BE HANDLED IN TOTALLY ENCLOSED SYSTEM. (4) (40)	HIGH POTENTIAL RISK DUE TO RISK OF HANDLING SO_2 IN PRESSURIZED CYLINDERS. (1) (10)
ENVIRONMENTAL RISK	10	LOW TO MODERATE DUE TO PRESENCE OF TOXIC O_3 IN EXHAUST GAS. (2) (20)	LOW (3) (30)	LOW (3) (30)	HIGH DUE TO POTENTIAL FOR RELEASE OF SO_2 GAS. (1) (10)
FLEXIBILITY					
WASTE QUANTITIES	7	SUITED TO BATCH TREATMENT PROCESSES BUT CAPACITY OF O_3 GENERATOR MAY BE LIMITING FACTOR AT HIGHER VOLUMES. (2) (10)	SAME AS Cl_2 (3) (15)	SAME AS Cl_2 (3) (15)	BETTER SUITED TO CONTINUOUS TREATMENT PROCESSES. CN REMOVAL EFFICIENCIES ARE HIGHER WITH CONTINUOUS TREATMENT THAN WITH BATCH TREATMENT. (2) (10)

TABLE A-1 (CON'T)
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	OZONE O_3	POTASSIUM PERMANGANATE $KMnO_4$	HYDROGEN PEROXIDE H_2O_2	AIR/SULPHUR DIOXIDE AIR/SO_2
FLEXIBILITY (con't)					
WASTE CHARACTERISTICS	7	CAPACITY OF O_3 GENERATOR MAY MAKE PROCESS MORE SENSITIVE TO VARYING FEED STRENGTHS COMPARED TO OTHERS. (2) (10)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)	HIGHER CONCENTRATIONS REQUIRE HIGHER REAGENT DOSES. (3) (15)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL			
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	ELECTRODES AND UV LAMPS ARE POTENTIALLY HIGH MAINTENANCE ITEMS. (1) (1)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE IS LOW. (3) (3)
SPARE PARTS	2	SPARE ELECTRODES AND/OR UV LAMPS ARE REQUIRED IN ADDITION TO USUAL SPARE PARTS INVENTORY. (2) (4)	SAME AS Cl_2 (3) (6)	SAME AS Cl_2 (3) (6)	SAME AS Cl_2 (3) (6)
AVAILABILITY OF PARTS AND REAGENTS	3	O_3 MUST BE GENERATED ON SITE. SPARES SHOULD BE READILY AVAILABLE. ELECTRODES AND LAMPS SHOULD BE STOCKED TO AVOID LONG DELIVERY. (2) (6)	$KMnO_4$ IS READILY AVAILABLE. (3) (9)	H_2O_2 IS READILY AVAILABLE. (3) (9)	AIR/SO_2 IS READILY AVAILABLE. COPPER CATALYST MAY HAVE TO BE ADDED TO SOME WASTES PRIOR TO (3) (9)
ROBUSTNESS OF EQUIPMENT	1	LESS ROBUST THAN CHEMICAL METHODS DUE TO RELIANCE ON O_3 GENERATOR. (1) (1)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	MORE VULNERABLE TO PROCESS BREAKDOWNS OR UPSETS DUE TO RELIANCE ON ELECTRODES AND UV LAMPS. (2) (6)	SAME AS OTHER CHEMICAL METHODS. (3) (24)	SAME AS OTHER CHEMICAL METHODS. (3) (24)	SAME AS OTHER CHEMICAL METHODS. (3) (24)

TABLE A-1 (CON'T)

COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	OZONE O_3	POTASSIUM PERMANGANATE $KMnO_4$	HYDROGEN PEROXIDE H_2O_2	AIR/SULPHUR DIOXIDE AIR/SO_2
OPERATIONS					
COMPLEXITY	6	EQUIPMENT IS MORE COMPLEX THAN CHEMICAL METHODS DUE TO NEED TO GENERATE O_3 ON SITE. (1) (6)	EQUIPMENT IS RELATIVELY SIMPLE. PROVISION MUST BE MADE FOR HANDLING GRANULAR $KMnO_4$ (3) (18)	EQUIPMENT IS VERY SIMPLE SINCE REAGENT IS DELIVERED AND FED AS A LIQUID. (4) (24)	EQUIPMENT IS RELATIVELY SIMPLE ALTHOUGH SOMEWHAT SPECIALIZED PROCEDURES ARE REQUIRED FOR HANDLING SO_2. (3) (18)
DEGREE OF AUTOMATION	3	DISCHARGE QUALITY CAN BE CONTROLLED BY VARYING REACTION TIME. (3) (9)	SAME AS Cl_2. (3) (9)	SAME AS Cl_2. (3) (9)	SAME AS Cl_2. (3) (9)
START UP ASSISTANCE	1	READILY AVAILABLE. MORE TRAINING REQUIRED DUE TO HIGHER COMPLEXITY OF EQUIPMENT. (2) (2)	READILY AVAILABLE. TRAINING IS STRAIGHTFORWARD. (4) (4)	READILY AVAILABLE. TRAINING IS STRAIGHTFORWARD. (4) (4)	READILY AVAILABLE. TRAINING IS IMPORTANT DUE TO HAZARD ASSOCIATED WITH POTENTIAL FOR RELEASE OF SO_2 GAS. (2) (2)
COMMERCIAL & ECONOMIC					
RESTRICTIONS ON USE	1	N/A (5) (5)	N/A (5) (5)	POSSIBLE LICENCE FEE OR ROYALTIES MAY APPLY IF "KASTONE" PROCESS IS USED. (4) (4)	INCO WOULD LIKELY REQUIRE LICENCE FEE OR ROYALTY FOR USE OF PROCESS. (3) (3)
COST	7	EQUIPMENT COSTS ARE HIGHER THAN FOR CHEMICAL OXIDATION EQUIPMENT DUE TO HIGHER COMPLEXITY. OPERATING COSTS DEPEND ON SIZE OF O_3 GENERATING EQUIPMENT BUT ARE GNERALLY MORE EXPENSIVE THAN Cl_2. (2) (14)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. $KMnO_4$ IS MANY TIMES MORE EXPENSIVE THAN Cl_2. (2) (14)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. H_2O_2 IS ALMOST TWICE AS EXPENSIVE AS Cl_2. (3) (21)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL OXIDATION METHODS. POTENTIALLY LESS EXPENSIVE THAN Cl_2 DEPENDING ON SOURCE OF SO_2. (5) (35)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
DELIVERY	1	SAME AS ELECTROLYSIS. (1) (1)	SAME AS Cl_2. (5) (5)	SAME AS Cl_2. (5) (5)	SAME AS Cl_2. (5) (5)

N/A - NOT APPLICABLE

TABLE A-1 (CON'T)
COMPARISON OF OXIDATION PROCESSES

SELECTION CRITERIA	WEIGHT	OZONE O_3	POTASSIUM PERMANGANATE $KMnO_4$	HYDROGEN PEROXIDE H_2O_2	AIR/SULPHUR DIOXIDE AIR/SO_2
CANADIAN BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUPPLY AND FABRICATION OF EQUIPMENT	2	IN SOME CASES, EQUIPMENT WILL BE FABRICATED IN U.S. (2) (4)	AVAILABLE IN CANADA (3) (6)	AVAILABLE IN U.S. (2) (4)	AVAILABLE IN ONTARIO (5) (10)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
TOTAL SCORES		223	254	282	232

TABLE A-2

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE REDUCTION PROCESSES

PROCESS	TOTAL SCORE
Sodium Bisulphite	264
Sodium Metabisulphite	248
Sodium Sulphite	244
Ferrous Sulphate	238
Sodium Hydrosulphite	217
Sulphur Dioxide	215
Sodium Borohydride	199
Electrolysis	198

Refer to pages A-12 to A-18 for comparison of reduction processes.

TABLE A-2
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	SULPHUR DIOXIDE SO_2	SODIUM METABISULPHITE $Na_2S_2O_5$	SODIUM BISULPHITE $NaHSO_3$
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	ALL PROCESSES CAN BE EXPECTED TO ACHIEVE EQUIVALENT PERFORMANCE			
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	CONSUMES ELECTRICAL POWER AND SCRAP IRON SOME PROCESSES CONSUME ELECTRODES (3) (6)	REQUIRES 0.9 KG SO_2/KG CrO_3 (4) (8)	REQUIRES 1.47 KG $Na_2S_2O_5$/KG CrO_3 (3) (6)	REQUIRES 1.56 KG $NaHSO_3$/KG CrO_3 (3) (6)
RESIDUE CHARACTERISTICS	2	AFTER NEUTRALIZATION SLUDGE VOLUME WOULD BE EQUIVALENT TO SO_2 AND SULPHITE BASED TECHNOLOGIES (3) (6)	SLUDGE VOLUME IS APPROX. 300 KG PER KG CrO_3 WHEN LIME IS USED AS NEUTRALIZING REAGENT (3) (6)	SLUDGE VOLUME IS COMPARABLE TO SO_2 (3) (6)	SLUDGE VOLUME IS COMPARABLE TO SO_2 (3) (6)
EXTENT USED ELSEWHERE	6	NOT WIDELY USED FOR Cr^{6+} REDUCTION (3) (18)	MOST COMMONLY USED METHOD FOR Cr^{6+} REDUCTION (5) (30)	FREQUENTLY USED AS ALTERNATIVE TO LIQUID SO_2 (4) (24)	CURRENTLY BEING USED IN SIMILAR FACILITIES IN EUROPE (5) (30)
SAFETY					
OCCUPATIONAL RISK	10	POTENTIALLY HAZARDOUS OR EXPLOSIVE BY-PRODUCT GASES (EG. CHLORINE, HYDROGEN) CAN BE EMITTED FROM ELECTRODES. QUANTITIES ARE RELATIVELY SMALL HOWEVER. (2) (20)	POTENTIAL RISK IS ASSOCIATED WITH HANDLING LIQUID SO_2 IN PRESSURIZED CYLINDERS. (1) (10)	POSSIBLE RISK FROM DUST DURING HANDLING. DUST IS IRRITATING TO NOSE AND THROAT. SO_2 GAS IS RELEASED SLOWLY IN STORAGE AND MORE RAPIDLY WHEN EXPOSED TO HEAT OR FIRE. (3) (30)	STABLE SOLUTION MAY EMIT SO_2 GAS SLOWLY. CAN BE STORED AND HANDLED IN COMPLETELY ENCLOSED SYSTEM (4) (40)
ENVIRONMENTAL RISK	10	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)	ACCIDENT OR OPERATOR ERROR COULD CAUSE LARGE RELEASE OF SO_2 GAS (1) (10)	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)
FLEXIBILITY					
WASTE QUANTITIES	7	REACTION TIMES ARE SHORT (MINUTES) THEREFORE NOT PARTICULARLY SENSITIVE TO FEED RATE CHANGE PARTICULARLY IN BATCH OPERATION (3) (21)	SAME AS ELECTROLYSIS (3) (21)	SAME AS ELECTROLYSIS (3) (21)	SAME AS ELECTROLYSIS (3) (21)

TABLE A-2 (CON'T)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	SULPHUR DIOXIDE SO_2	SODIUM METABISULPHITE $Na_2S_2O_5$	SODIUM BISULPHITE $NaHSO_3$
FLEXIBILITY (con't)					
WASTE CHARACTERISTICS	7	BATCH TIME WILL VARY SOMEWHAT WITH CHANGES IN CONTAMINANT CONCENTRATION (2) (14)	REAGENT DEMAND WILL VARY WITH CHANGES IN CONTAMINANT CONCENTRATION (3) (21)	SAME AS SO_2 (3) (21)	SAME AS SO_2 (3) (21)
RAPID START UP/SHUT DOWN	6		ALL PROCESSES ARE JUDGED TO BE EQUAL		
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	ELECTRODES ARE A POTENTIALLY HIGH MAINTENANCE ITEM DUE TO SCALING AND FOULING (1) (1)	EQUIPMENT IS SIMPLE, THEREFORE MAINTENANCE WILL BE LOW (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)
SPARE PARTS	2	SPARE ELECTRODES REQUIRED IN ADDITION TO "NORMAL" SPARE PARTS INVENTORY (1) (2)	REQUIRES "NORMAL" SPARE PARTS INVENTORY FOR PUMPS AND AGITATORS (3) (6)	SAME AS SO_2 (3) (6)	SAME AS SO_2 (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	READILY AVAILABLE FROM EQUIPMENT SUPPLIER (3) (9)	READILY AVAILABLE (3) (9)	READILY AVAILABLE (3) (9)	READILY AVAILABLE (3) (9)
ROBUSTNESS OF EQUIPMENT	1	LESS ROBUST THAN CHEMICAL METHODS. ELECTRODES CAN BE SUSCEPTIBLE TO SCALING (1) (1)	EQUIPMENT IS SIMPLE AND ROBUST. (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	MORE VULNERABLE TO PROCESS UPSETS COMPARED TO CHEMICAL METHODS DUE TO POSSIBILITY OF ELECTRODE FAILURE (2) (16)	EQUIPMENT IS SIMPLE AND THEREFORE NOT PARTICULARLY SUSCEPTIBLE TO BREAKDOWN (4) (32)	SAME AS SO_2 (4) (32)	SAME AS SO_2 (4) (32)
OPERATIONS					
COMPLEXITY	6	MORE COMPLEX THAN CHEMICAL BASED REDUCTION ALTERNATIVES DUE TO COMPLEXITY OF EQUIPMENT (1) (6)	MORE COMPLEX THAN OTHER CHEMCIAL REDUCTION ALTERNATIVES DUE TO SAFETY FEATURES REQUIRED TO HANDLE PRESSURIZED LIQUID SO_2 (2) (12)	EQUIPMENT IS SIMPLE (3) (18)	EQUIPMENT IS SIMPLE (3) (18)

TABLE A-2 (CONT'D)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	ELECTROLYSIS	SULPHUR DIOXIDE SO_2	SODIUM METABISULPHITE $Na_2S_2O_5$	SODIUM BISULPHITE $NaHSO_3$
OPERATIONS (con't)					
DEGREE OF AUTOMATION	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
START UP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COMMERCIAL & ECONOMIC					
RESTRICTIONS ON USE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COST	7	EQUIPMENT COSTS ARE GENERALLY HIGHER THAN FOR CHEMICAL REDUCTION METHODS DUE TO HIGHER COMPLEXITY OF EQUIPMENT. OPERATING COSTS ARE SLIGHTLY LOWER THAN SO_2 REDUCTION BASED ON POWER REQUIREMENTS (4) (28)	EQUIPMENT COSTS ARE COMPARABLE TO OTHER CHEMICAL METHODS. SO_2 COST IS LESS THAN OTHER REAGENTS IF PURCHASED IN TANK CAR LOTS. (4) (28)	EQUIPMENT COSTS ARE COMPARABLE TO SO_2 METHOD. REAGENT COST IS SLIGHTLY HIGHER THAN SO_2 (3) (21)	SAME AS $NA_2S_2O_5$ (3) (21)
SUPPLIER COMPETION AND RELIABILITY	1	ADEQUATE (3) (3)	ADEQUATE (3) (3)	ADEQUATE (3) (3)	ADEQUATE (3) (3)
DELIVERY	1	POTENTIALLY LONGER DUE TO NEED FOR MORE COMPLEX EQUIPMENT (1) (1)	NOT A PROBLEM (3) (3)	NOT A PROBLEM (3) (3)	NOT A PROBLEM (3) (3)
CANADIAN BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUPPLY AND FABRICATION OF EQUIPMENT	2	AVAILABLE IN CANADA (3) (6)	MADE IN ONTARIO (5) (10)	IMPORTED FROM EUROPE (1) (2)	MADE FROM IMPORTED SODIUM METABISULPHITE (1) (2)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
TOTAL SCORES		198	215	248	264

TABLE A-2 (CONT'D)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	SODIUM HYDROSULPHITE $Na_2S_2O_4$	SODIUM SULPHITE Na_2SO_3	FERROUS SULPHATE $FeSO_4$ o $7H_2O$	SODIUM BOROHYDRIDE $NaBH_4$
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	ALL PROCESSES CAN BE EXPECTED TO ACHIEVE EQUIVALENT PERFORMANCE			
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	REQUIRES 2.61 KG $Na_2S_2O_4$/ KG CrO_3 (2) (4)	REQUIRES 1.89 KG Na_2SO_3/ KG CrO_3 (3) (6)	REQUIRES 8.34 KG $FeSO_4$ o $7H_2O$/KG CrO_3 IRON CAN CAUSE FORMATION OF IRON CYANIDE COMPLEXES IF CYANIDE IS PRESENT (1) (2)	REQUIRES 0.14 KG $NaBH_4$/ KG CrO_3 TO REDUCE Cr^{6+} TO Cr^{3+} (5) (10)
RESIDUE CHARACTERISTICS	2	SLUDGE VOLUME IS COMPARABLE TO SO_2 (3) (6)	SLUDGE VOLUE IS COMPARABLE TO SO_2 (3) (6)	SLUDGE VOLUME IS MUCH HIGHER (APPROX. 4 TIMES) COMPARED TO OTHER CHEMICAL REDUCTION PROCESSES (1) (2)	SLUDGE VOLUME IS COMPARABLE TO OTHER PROCESSES BUT BORATE IS MORE DIFFICULT TO REMOVE BY SUBSEQUENT TREATMENT STEPS COMPARED TO SULPHATE. (1)
EXTENT USED ELSEWHERE	6	NOT WIDELY USED FOR Cr^6 REDUCTION (2) (12)	BISULPHITE OR LIQUID SO_2 ARE MORE COMMONLY USED (3) (18)	NOT OFTEN USED UNLESS WASTE CONTAINING $FeSO_4$ o $7H_2O$ (EG. PICKLING LIQUOR) IS AVAILABLE (3) (18)	MORE OFTEN USED FOR LEAD AND MERCURY REDUCTION NOT A WIDESPREAD USE FOR Cr^{6+} (2) (12)
SAFETY					
OCCUPATIONAL RISK	10	VERY REACTIVE. MAY IGNITE IF ALLOWED TO BECOME DAMP. (2) (20)	STABLE SOLID MAY IRRITATE EYES AND NOSE (3) (30)	STABLE SOLID MAY CAUSE SLIGHT IRRITATION (3) (30)	SOME RISK OF EXPLOSION DUE TO FACT THAT SOLUTIONS WILL DECOMPOSE AND EVOLVE HYDROGEN IF OVERHEATED, SUBJECTED TO ACID CONDITIONS OR BROUGHT INTO CONTACT WITH FINELY DIVIDED METAL PRECIPITATES (2) (20)
ENVIRONMENTAL RISK	10	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)	MINIMAL RISK DURING NORMAL OR UPSET CONDITIONS (4) (40)

TABLE A-2 (CONT'D)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	SODIUM HYDROSULPHITE $Na_2S_2O_4$	SODIUM SULPHITE Na_2SO_3	FERROUS SULPHATE $FeSO_4 \circ 7H_2O$	SODIUM BOROHYDRIDE $NaBH_4$
FLEXIBILITY					
WASTE QUANTITIES	7	SAME AS ELECTROLYSIS (3) (21)	SAME AS ELECTROLYSIS (3) (21)	SAME AS ELECTROLYSIS (3) (21)	SAME AS ELECTROLYSIS (3) (21)
WASTE CHARACTERISTICS	7	SAME AS SO_2 (3) (21)	SAME AS SO_2 (3) (21)	SAME AS SO_2 (3) (21)	SAME AS SO_2 (3) (21)
RAPID START UP/SHUTDOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL			
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)
SPARE PARTS	2	SAME AS SO_2 (3) (6)	SAME AS SO_2 (3) (6)	SAME AS SO_2 (3) (6)	SAME AS SO_2 (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	READILY AVAILABLE (3) (9)	READILY AVAILABLE (3) (9)	READILY AVAILABLE (3) (9)	AVAILABLE FROM MORE RESTRICTED NUMBER OF SUPPLIERS COMPARED TO OTHER REAGENTS (1) (3)
ROBUSTNESS OF EQUIPMENT	1	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)	SAME AS SO_2 (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	SAME AS SO_2 (4) (32)	SAME AS SO_2 (4) (32)	SAME AS SO_2 (4) (32)	SAME AS SO_2 (4) (32)
OPERATIONS					
COMPLEXITY	6	MORE COMPLEX THAN CHEMICAL BASED REDUCTION ALTERNATIVES (3) (18)	MORE COMPLEX THAN OTHER CHEMICAL REDUCTION ALTERNATIVES DUE TO SAFETY FEATURES REQUIRED TO HANDLE PRESSURIZED LIQUID SO_2 (3) (18)	EQUIPMENT IS SIMPLE (3) (18)	EQUIPMENT IS SIMPLE (3) (18)

TABLE A-2 (CONT'D)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	SODIUM HYDROSULPHITE $Na_2S_2O_4$	SODIUM SULPHITE Na_2SO_3	FERROUS SULPHATE $FeSO_4 \circ 7H_2O$	SODIUM BOROHYDRIDE $NaBH_4$
OPERATIONS (con't)					
DEGREE OF AUTOMATION	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
START UP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COMMERCIAL & ECONOMIC					
RESTRICTIONS OF USE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COST	7	EQUIPMENT COSTS ARE COMPARABLE TO SO_2 METHOD. REAGENT COST IS MUCH HIGHER THAN SO_2 (2) (14)	EQUIPMENT COSTS ARE COMPARABLE TO SO_2 METHOD. REAGENT COST IS SLIGHTLY HIGHER THAN SO_2 (3) (21)	EQUIPMENT COSTS ARE COMPARABLE TO SO_2 METHOD. REAGENT COST IS HIGHER THAN SO_2 IF WASTE PICKLING LIQUOR OR EQUIVALENT IS NOT AVAILABLE. (3) (21)	EQUIPMENT COSTS ARE COMPARABLE TO SO_2 METHOD. REAGENT COST IS HIGHEST OF ALL OPTIONS. (1) (7)
SUPPLIER COMPETITION AND RELIABILITY	1	ADEQUATE (3) (3)	ADEQUATE (3) (3)	ADEQUATE (3) (3)	ONLY AVAILABLE FROM A LIMITED NUMBER OF SUPPLIERS (1) (1)
DELIVERY	1	NOT A PROBLEM (3) (3)	NOT A PROBLEM (3) (3)	NOT A PROBLEM (3) (3)	POTENTIALLY LONGER DUE TO SPECIALIZED NATURE OF REAGENT AND LIMITED SUPPLIERS (2) (2)
CANADIAN BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			

TABLE A-2 (CONT'D)
COMPARISON OF REDUCTION PROCESSES

SELECTION CRITERIA	WEIGHT	SODIUM HYDROSULPHITE $Na_2S_2O_4$	SODIUM SULPHITE Na_2SO_3	FERROUS SULPHATE $FeSO_4 \cdot 7H_2O$	SODIUM BOROHYDRIDE $NaBH_4$
CANADIAN BENEFITS (con't)					
SUPPLY AND FABRICATION OF EQUIPMENT	2	NOT READILY AVAILABLE (1) (2)	IMPORTED FROM U.S. (2) (4)	MADE IN QUEBEC (3) (6)	IMPORTED FROM U.S. (2)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESS ARE JUDGED TO BE EQUAL			
TOTAL SCORES		217	244	238	199

TABLE A-3

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE SECONDARY PHASE SEPARATION PROCESSES

(FOR SOLIDS/LIQUID SEPARATION)

PROCESS	TOTAL SCORE
Sedimentation	343
Filtration	287
Centrifugation	251
Air Flotation	238
High Gradient Magnetic Separation	170

Refer to pages A-20 to A-22 for comparison of secondary solids liquid separation processes.

TABLE A-3
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR SOLIDS/LIQUID SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	HIGH GRADIENT MAGNETIC SEPARATION	AIR FLOTATION
PERFORMANCE						
MOST EFFECTIVE TREATMENT	10	CAPABLE OF ACHIEVING VERY EFFECTIVE SUSPENDED SOLIDS REMOVALS WITH PROPER USE OF POLYMERS (3) (30)	POTENTIALLY CAPABLE OF BEST EFFLUENT QUALITY OF ALL OPTIONS DEPENDING ON TYPE OF EQUIPMENT USED (4) (40)	NOT WELL SUITED TO HYDROXIDE SLUDGES WHICH ARE PRONE TO FLOC BREAK UP DUE TO HIGH SHEAR (2) (20)	NOT WELL SUITED TO GENERAL SOLIDS SEPARATION APPLICATIONS (1) (10)	CAPABLE OF ACHIEVING VERY EFFECTIVE SUSPENDED SOLIDS REMOVALS WITH PROPER USE OF POLYMERS (3) (30)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	MOST ENERGY EFFICIENT OF ALL OPTIONS. REAGENT USE IS MINIMAL. (5) (10)	LOW ENERGY USE PARTICULARLY FOR GRAVITY FILTRATION MINIMAL REAGENT USE. (4) (8)	MODERATE ENERGY USE. MINIMAL REAGENT USE. (3) (6)	MODERATE TO HIGH ENERGY USE. SEEDING WITH MAGNETIC PARTICLES LIKELY REQUIRED. (2) (4)	MODERATE ENERGY USE. MINIMAL REAGENT USE. (3) (6)
RESIDUE CHARACTERISTICS	2	POST TREATMENT REQ'D FOR SLUDGE AND MAY BE REQ'D FOR SUPERNATANT (3) (6)	POST TREATMENT USUALLY NOT REQ'D FOR FILTRATE, BUT USUALLY REQ'D FOR BACKWASH WATER (3) (6)	POST TREATMENT REQ'D FOR SUPERNATANT BUT USUALLY NOT FOR SLUDGE (3) (6)	POST TREATMENT MAY BE REQ'D FOR SLUDGE (3) (6)	POST TREATMENT REQ'D FOR SLUDGE AND MAY BE REQ'D FOR SUPERNATANT (3) (6)
EXTENT USED ELSEWHERE	6	WIDELY USED (3) (18)	WIDELY USED (3) (18)	WIDELY USED (3) (18)	LESS WIDELY USED THAN OTHER PROCESSES (1) (6)	WIDELY USED (3) (18)
SAFETY						
OCCUPATIONAL RISK	10	NO SIGNIFICANT RISK (5) (50)	SIGNIFICANT RISK FOR GRAVITY FILTERS. LOW RISK FOR PRESSURE FILTERS (4) (40)	MODERATE TO HIGH DUE TO SAFETY AND NOISE HAZARD OF HIGH SPEED OPERATION (2) (20)	MODERATE DUE TO HIGH DENSITY MAGNETIC FIELD (3) (30)	MODERATE DUE TO PRESSURIZED RETURN LOOP (3) (30)
ENVIRONMENTAL RISK	10	LOW RISK (4) (40)	LOW RISK (4) (40)	LOW RISK (4) (40)	LOW RISK (4) (40)	POTENTIAL RISK DUE TO AIR EMISSIONS BUT ONLY IF ORGANICS ARE PRESENT. (2) (20)
FLEXIBILITY						
WASTE QUANTITIES	7	ALL PROCESSES ARE JUDGED TO BE EQUAL				

TABLE A-3 (CON'T)
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR SOLIDS/LIQUID SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	HIGH GRADIENT MAGNETIC SEPARATION	AIR FLOTATION
FLEXIBILITY (con't)						
WASTE CHARACTERISTICS	7	SUITABLE FOR A WIDE RANGE OF SOLIDS CONCENTRATIONS (5) (35)	LESS FLEXIBLE THAN SEDIMENTATION (3) (21)	LESS FLEXIBLE THAN SEDIMENTATION BUT MORE FLEXIBLE THAN FILTRATION (4) (28)	LEAST FLEXIBLE OF ALL OPTIONS (1) (7)	LESS FLEXIBLE THAN SEDIMENTATION, FILTRATION AND CENTRIFUGATION (2) (14)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL				
RELIABILITY						
MAINTENANCE REQUIREMENTS	1	LITTLE OR NO MAINTENANCE REQ'D (5) (5)	MODERATE TO LOW (3) (3)	MODERATE TO HIGH DUE TO HIGH SPEED OPERATION (2) (2)	LIKELY MODERATE TO HIGH DUE TO HIGHER COMPLEXITY OF EQUIPMENT (2) (2)	MODERATE TO LOW (3) (3)
SPARE PARTS	2	NONE REQUIRED OTHER THAN `NORMAL' SPARE PARTS (5) (10)	SPARE FILTER MEDIA REQUIRED (3) (6)	SPARE BEARINGS AND OTHER MECHANICAL PARTS REQUIRED (3) (6)	SPARE ELECTRICAL COMPONENTS OF POTENTIALLY SPECIALIZED NATURE (2)(4)	SPARE PUMP AND COMPRESSOR PARTS REQUIRED (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	N/A (5) (15)	READILY AVAILABLE (4) (12)	READILY AVAILABLE (4) (12)	LESS READILY AVAILABLE DUE TO NATURE OF PROCESS (2) (6)	READILY AVAILABLE (4) (12)
ROBUSTNESS OF EQUIPMENT	1	MOST ROBUST OF ALL PROCESSES (5) (5)	GENERALLY VERY ROBUST (3) (3)	GENERALLY VERY ROBUST (3) (3)	LITTLE OPERATING DATA AVAILABLE TO JUDGE (2) (2)	GENERALLY VERY ROBUST (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	LITTLE VULNERABILITY PARTICULARLY WHEN OPERATED BATCHWISE (4) (32)	MODERATE (3) (24)	MODERATE (3) (24)	MODERATE TO HIGH (2) (16)	MODERATE (3) (24)
OPERATIONS						
COMPLEXITY	6	SIMPLEST OF ALL ALTERNATIVES (4) (24)	RELATIVELY SIMPLE (3) (18)	RELATIVELY SIMPLE (3) (18)	RELATIVELY COMPLEX (2) (12)	RELATIVELY SIMPLE (3) (18)

N/A - NOT APPLICABLE

TABLE A-3 (CONT'D)
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR SOLIDS/LIQUID SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	HIGH GRADIENT MAGNETIC SEPARATION	AIR FLOTATION
OPERATIONS (con't)						
DEGREE OF AUTOMATION	3	DIFFICULT TO AUTOMATE. DISCHARGE QUALITY IS EASY TO CONTROL (3) (9)	EASY TO AUTOMATE. DISCHARGE QUALITY MORE DIFFICULT TO CONTROL (3) (9)	EASY TO AUTOMATE. DISCHARGE QUALITY MORE DIFFICULT TO CONTROL (3) (9)	EASY TO AUTOMATE DISCHARGE QUALITY MORE DIFFICULT TO CONTROL (3) (9)	EASY TO AUTOMATE. DISCHARGE QUALITY MORE DIFFICULT TO CONTROL (3) (9)
START UP ASSISTANCE	1	READILY AVAILABLE (3) (3)	READILY AVAILABLE (3) (3)	READILY AVAILABLE (3) (3)	LESS READILY AVAILABLE (1) (1)	READILY AVAILABLE (3) (3)
COMMERCIAL & ECONOMIC						
RESTRICTIONS ON USE	1	N/A (3) (3)	N/A (3) (3)	N/A (3) (3)	MAY BE APPLICABLE (1) (1)	N/A (3) (3)
COST	7	LOW CAPITAL AND OPERATING COST (5) (35)	MODERATE CAPITAL AND OPERATING COST (3) (21)	MODERATE CAPITAL OPERATING COST (3) (21)	HIGH CAPITAL AND OPERATING COST (1) (7)	MODERATE CAPITAL AND OPERATING COST (3) (21)
SUPPLIER COMPETITION AND RELIABILITY	1	SUFFICIENT (3) (3)	SUFFICIENT (3) (3)	SUFFICIENT (3) (3)	LIMITED (1) (1)	SUFFICIENT (3) (3)
DELIVERY	1	SHORT (4) (4)	MODERATE (3) (3)	MODERATE (3) (3)	POTENTIALLY LONG (2) (2)	MODERATE (3) (3)
CANADIAN BENEFITS		ALL PROCESSES ARE JUDGED TO BE EQUAL				
ENGINEERING	1					
SUPPLY AND FABRICATION OF EQUIPMENT	2	CAN BE FABRICATED IN CANADA (3) (6)	AVAILABLE IN CANADA (3) (6)	AVAILABLE IN CANADA (3) (6)	MAY NOT BE AVAILABLE IN CANADA (2) (4)	AVAILABLE IN CANADA (3) (6)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL				
	TOTAL SCORES	343	287	251	170	238

N/A - NOT APPLICABLE

TABLE A-4

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE SECONDARY PHASE SEPARATION PROCESSES

(FOR OIL/WATER SEPARATION)

PROCESS	TOTAL SCORE
Sedimentation	331
Centrifugation	292
Air Flotation	283
Filtration	270

Refer to pages A-24 to A-26 for comparison of secondary oil/water separation processes.

TABLE A-4
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR OIL/WATER-SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	AIR FLOTATION
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	OFTEN LESS EFFECTIVE THAN ALTERNATIVE METHODS FOR DIFFICULT TO TREAT WASTES (2) (20)	VERY EFFECTIVE WITH PROPER USE OF COAGULANT AIDS (3) (30)	VERY EFFECTIVE WITH PROPER USE OF COAGULANT AIDS (3) (30)	VERY EFFECTIVE WITH PROPER USE OF COAGULANT AIDS. ADDITIONAL REMOVALS OF VOLATILE ORGANICS WILL OCCUR BY AIR STRIPPING (40) (40)
EFFICIENCY: ENERGY UTILITIES, REAGENTS,	2	LEAST ENERGY INTENSIVE PROCESS. REQUIRES COAGULENT AIDS FOR BEST PERFORMANCE. (5) (10)	REQUIRES COAGULANT AIDS AND, IN SOME CASES, FILTER AID FOR BEST PERFORMANCE PRECOAT REQUIREMENTS MAY BE QUITE HIGH FOR SOME WASTES (2) (4)	REQUIRES COAGULANT AIDS FOR BEST PERFORMANCE MOST ENERGY INTENSIVE PROCESS. (3) (6)	REQUIRES COAGULANT AIDS FOR BEST PERFORMANCE. MORE ENERGY INTENSIVE THAN SEDIMENTATION (4) (8)
RESIDUE CHARACTERISTICS	2	RECOVERED OIL MAY HAVE HIGH WATER CONTENT BUT EASILY PUMPED. RECOVERED WATER GENERALLY REQUIRES FURTHER TREATMENT (3) (6)	RECOVERED OIL LIKELY TO BE CONTAMINATED WITH FILTER AID. FILTER CAKE OR CONTAMINATED FILTER PAPER WILL BE HARD TO HANDLE. (2) (4)	RECOVERED OIL SHOULD HAVE LOWER WATER CONTENT THAN ACHIEVABLE BY SEDIMENTATION. RECOVERED WATER GENERALLY REQUIRES FURTHER TREATMENT (4) (8)	RECOVERED OIL MAY HAVE HIGH AIR AND WATER CONTENT BUT EASILY PUMPED. VENTED AIR REQUIRES TREATMENT FOR REMOVAL OF ORGANICS. (2) (4)
EXTENT USED ELSEWHERE	6	WIDELY USED (5) (30)	LESS OFTEN USED FOR BULK OIL/WATER SEPARATION APPLICATIONS COMPARED TO OTHER PROCESSES (3) (18)	WIDELY USED (5) (30)	WIDELY USED (5) (30)
SAFETY					
OCCUPATIONAL RISK	10	VERY LOW SINCE NO ROTATING MACHINERY IS INVOLVED (5) (50)	HIGHER THAN SEDIMENTATION DUE TO LARGER NUMBER OF MOVING PARTS (4) (40)	MODERATE DUE TO SAFETY AND NOISE HAZARD OF HIGH SPEED OPERATION (3) (30)	MODERATE DUE TO PRESSURIZED RETURN LOOP AND RISK OF FUGITIVE EMISSIONS FROM VENTILATION AIR SYSTEM (3) (30)
ENVIRONMENTAL RISK	10	LOW RISK (4) (40)	LOW RISK (4) (40)	LOW RISK (4) (40)	SLIGHTLY HIGHER RISK COMPARED TO OTHER PROCESSES IN THE EVENT OF FAILURE OF VENTILATION AIR COLLECTION AND SCRUBBING SYSTEM (3) (30)

TABLE A-4 (CONT'D)
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR OIL/WATER-SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	AIR FLOTATION
FLEXIBILITY					
WASTE QUANTITIES	7	LONGER SETTLING TIMES CAN POTENTIALLY LIMIT FLEXIBILITY (2) (14)	MODERATELY SENSITIVE. MAX. FEED RATE WILL BE LIMITED BY EQUIPMENT DESIGN (3) (21)	RELATIVELY INSENSITIVE TO CHANGES IN FEEDRATE DUE TO SHORT RESIDENCE TIME (4) (28)	MODERATELY SENSITIVE. MAX. FEED RATE WILL BE LIMITED BY EQUIPMENT DESIGN (3) (21)
WASTE CHARACTERISTICS	7	SUITABLE FOR WIDE RANGE OF CONCENTRATIONS (4) (28)	BEST FOR LOWER RANGE OF CONCENTRATIONS AND RESIDUAL OIL REMOVAL (2) (14)	SUITABLE FOR WIDE RANGE OF CONCENTRATIONS (4) (28)	SUITABLE FOR RELATIVELY WIDE RANGE OF CONCENTRATIONS INCLUDING RESIDUAL OIL REMOVAL (3) (21)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL			
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	LITTLE OR NO MAINTENANCE REQUIRED (5) (5)	MODERATE (3) (3)	MODERATE TO HIGH DUE TO HIGH SPEED OPERATION (2) (2)	MODERATE (3) (3)
SPARE PARTS	2	NONE REQUIRED (5) (10)	SPARE FILTER MEDIA REQ'D (3) (6)	SPARE BEARINGS OR OTHER MECHANICAL PARTS REQ'D (3) (6)	SPARE PUMP AND COMPRESSOR PARTS REQ'D (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	N/A (5) (15)	READILY AVAILABLE (4) (12)	READILY AVAILABLE (4) (12)	READILY AVAILABLE (4) (12)
ROBUSTNESS OF EQUIPMENT	1	MOST ROBUST OF ALL PROCESSES (5) (5)	GENERALLY VERY ROBUST (3) (3)	GENERALLY VERY ROBUST (3) (3)	GENERALLY VERY ROBUST (3) (3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	LITTLE VULNERABILITY PARTICULARLY WHEN OPERATED BATCHWISE (4) (32)	MODERATE (3) (24)	MODERATE (3) (24)	MODERATE (3) (24)
OPERATIONS					
COMPLEXITY	6	SIMPLEST OF ALL ALTERNATIVES (4) (24)	RELATIVELY SIMPLE (3) (18)	RELATIVELY SIMPLE (3) (18)	RELATIVELY SIMPLE (3) (18)

TABLE A-4 (CONT'D)
COMPARISON OF SECONDARY PHASE SEPARATION PROCESSES
(FOR OIL/WATER-SEPARATION)

SELECTION CRITERIA	WEIGHT	SEDIMENTATION	FILTRATION	CENTRIFUGATION	AIR FLOTATION
OPERATIONS (con't)					
DEGREE OF AUTOMATION	3	DIFFICULT TO AUTOMATE RETREATMENT LIKELY TO BE INEFFECTIVE (1) (3)	EASY TO AUTOMATE RETREATMENT LIKELY TO BE EFFECTIVE (3) (9)	EASY TO AUTOMATE RETREATMENT LIKELY TO BE INEFFECTIVE (1) (3)	EASY TO AUTOMATE RETREATMENT LIKELY TO BE EFFECTIVE (3) (9)
START UP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COMMERCIAL & ECONOMIC		ALL PROCESSES ARE JUDGES TO BE EQUAL			
RESTRICTIONS ON USE	1				
COST	7	LOW CAPITAL AND OPERATING COST (5) (35)	MODERATE CAPITAL AND OPERATING COSTS (3) (21)	MODERATE CAPITAL AND OPERATING COST (3) (21)	MODERATE CAPITAL AND OPERATING COST (3) (21)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESS ARE JUDGED TO BE EQUAL			
DELIVERY	1	SHORT (4) (4)	MODERATE (3) (3)	MODERATE (3) (3)	MODERATE (3) (3)
CANADIAN BENEFITS		ALL PROCESSES ARE JUDGED TO BE EQUAL			
ENGINEERING	1	N/A	N/A	N/A	N/A
SUPPLY AND FABRICATION OF EQUIPMENT	2	ALL PROCESSES ARE JUDGED TO BE EQUAL (3) (6)	(3) (6)	(3) (6)	(3) (6)
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
TOTAL SCORES		331	270	292	283

N/A - NOT APPLICABLE

TABLE A-5

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE SLUDGE DEWATERING PROCESSES

PROCESS	TOTAL SCORE
Pressure Filtration	218
Vacuum Filtration	192
Centrifugation	162
Belt Filter Press	138

Refer to pages A-28 to A-30 for comparison of sludge dewatering processes.

TABLE A-5
COMPARISON OF SLUDGE DEWATERING PROCESSES

SELECTION CRITERIA	WEIGHT	CENTRIFUGATION	PRESSURE FILTRATION	VACUUM FILTRATION	BELT FILTER PRESS
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	CAKE DENSITIES ARE LOWER THAN FOR FILTRATION OPTIONS (2) (20)	HIGHEST CAKE DENSITIES ATTAINABLE FOR ALL OPTIONS 30-40 WT% (5) (50)	CAKE DENSITIES ARE CLOSE TO THOSE OF PRESSURE FILTRATION 20-30 WT% (4) (40)	MAINLY SUITED TO FIBROUS COMPRESSIBLE SLUDGES NOT WELL SUITED TO GELATENOUS NON-COMRESSIBLE HYDROXIDE SLUDGES (1) (10)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	ENERGY USED IS COMPARABLE TO PRESSURE AND VACUUM FILTRATION. REQUIRES USE OF COAGULANT AIDS FOR MAXIMUM PERFORMANCE (3) (6)	ENERGY USE IS COMPARABLE TO CENTRIFUGATION AND VACUUM FILTRATION. REQUIRES USE OF COAGULANT AIDS AND POSSIBLY FILTER AIDS FOR MAXIMUM PERFORMANCE (2) (4)	ENERGY USE IS COMPARABLE TO CENTRIFUGATION AND PRESSURE FILTRATION. REQUIRES USE OF COAGULANT AIDS AND POSSIBLE FILTER AIDS FOR MAXIMUM PERFORMANCE (2) (4)	ENERGY USE IS GENERALLY LOWER THAN OTHER PROCESSES. COAGULANT AIDS REQUIRED FOR MAXIMUM PERFORMANCE (4) (8)
RESIDUE CHARACTERISTICS	2	SOLIDS MAY REQUIRE FURTHER DEWATERING FOR EASY HANDLING. CENTRATE WILL LIKELY REQUIRE FURTHER TREATMENT (2) (4)	CAKE IS SUITABLE FOR SOLIDIFICATION. FILTRATE GENERALLY DOES NOT REQUIRE FURTHER TREATMENT (4) (8)	CAKE IS SUITABLE FOR SOLIDIFICATION. FILTRATE GENERALLY DOES NOT REQUIRE FURTHER TREATMENT (4) (8)	SOLIDS MAY REQUIRE FURTHER DEWATERING FOR EASY HANDLING. FILTRATE MAY REQUIRE FURTHER TREATMENT. (2) (4)
EXTENT USED ELSEWHERE	6	WIDELY USED (3) (18)	MOST WIDELY USED THIS TYPE OF APPLICATION (4) (24)	WIDELY USED (3) (18)	LEASE WIDELY USED FOR THIS TYPE OF APPLICATION (2) (12)
SAFETY					
OCCUPATIONAL RISK	10	MODERATE DUE TO SAFETY AND NOISE HAZARD OF HIGH SPEED OPERATION (3) (30)	LOW - PROCESS IS COMPLETELY CLOSED (4) (40)	LOW PROVIDED THAT DRUM IS ENCLOSED TO CONTAIN ODOURS (4) (40)	LOW PROVIDED THAT UNIT IS ENCLOSED TO CONTAIN ORDOURS (4) (40)
ENVIRONMENTAL RISK	10		ALL PROCESSES ARE JUDGED	TO BE EQUAL	
FLEXIBILITY					
WASTE QUANTITIES	7	RELATIVELY INSENSITIVE DUE TO SHORT RESIDENCE TIME (4) (28)	RELATIVELY INSENSITIVE HIGHER FEEDRATES WILL RESULT IN SHORTER CYCLE TIMES (4) (28)	LESS ABLE TO HANDLE HIGHER VOLUMES OF DILUTE SLUDGES COMPARED TO PRESSURE FILTRATION (3) (21)	MAX. FEED RATE WILL BE LIMITED BY EQUIPMENT DESIGN (2) (14)

TABLE A-5 (CON'T)
COMPARISON OF SLUDGE DEWATERING PROCESSES

SELECTION CRITERIA	WEIGHT	CENTRIFUGATION	PRESSURE FILTRATION	VACUUM FILTRATION	BELT FILTER PRESS
FLEXIBILITY (con't)					
WASTE CHARACTERISTICS	7	NOT AS WELL SUITED TO VERY DILUTE SLUDGES (< 2 WT%) (2) (14)	WELL SUITED TO A WIDE RANGE OF SLUDGES. MAY REQUIRE PRECOAT (4) (28)	WELL SUITED TO A WIDE RANGE OF SLUDGES. MAY REQUIRE PRECOAT (4) (28)	NOT AS WELL SUITED TO GELATENOUS SLUDGES (2) (14)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL			
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	MODERATE (3) (3)	MODERATE (3) (3)	MODERATE TO HIGH DUE TO VACUUM SYSTEM (2) (2)	MODERATE (3) (3)
SPARE PARTS	2	SPARE BEARINGS AND OTHER MECHANICAL PARTS REQ'D (3) (6)	SPARE FILTER CLOTH REQ'D (3) (6)	SPARE FILTER CLOTH AND VACUUM SYSTEM PARTS REQ'D (2) (4)	SPARE FILTER BELT AND OTHER MECHANICAL PARTS REQ'D (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
ROBUSTNESS OF EQUIPMENT	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	ALL PROCESSES ARE JUDGED TO BE EQUAL			
OPERATIONS					
COMPLEXITY	6	RELATIVELY SIMPLE (4) (24)	RELATIVELY SIMPLE (4) (24)	MORE COMPLEX THAN PRESSURE FILTRATION DUE TO VACUUM SYSTEM (3) (18)	MORE COMPLEX DUE TO LENGTH OF BELT AND NUMBER OF GUIDE ROLLERS (3) (18)
DEGREE OF AUTOMATION	3	MODERATE (3) (9)	MORE OPERATOR INVOLVEMENT BECAUSE OF REQUIREMENT FOR MANUAL CAKE DISCHARGE (1) (3)	MODERATE (3) (9)	MODERATE (3) (9)
START UP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COMMERCIAL & ECONOMIC					
RESTRICTIONS ON USE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COST	7	ALL PROCESSES ARE JUDGED TO BE EQUAL			

TABLE A-5 (CON'T)
COMPARISON OF SLUDGE DEWATERING PROCESSES

SELECTION CRITERIA	WEIGHT	CENTRIFUGATION	PRESSURE FILTRATION	VACUUM FILTRATION	BELT FILTER PRESS
COMMERCIAL & ECONOMIC (con't)					
OPERATING COST	1	COMPARABLE TO OTHER PROCESSES (3) (3)	HIGHER BECAUSE OF GREATER OPERATOR INVOLVEMENT (1) (1)	COMPARABLE TO OTHER PROCESSES (3) (3)	COMPARABLE TO OTHER PROCESSES (3) (3)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
DELIVERY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
CANADIAN BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUPPLY AND FABRICATION OF EQUIPMENT	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE ALL JUDGED TO BE EQUAL			
TOTAL SCORES		162	218	192	138

TABLE A-6

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE POLISHING PROCESSES TO REMOVE SUSPENDED SOLIDS AND IMMISCIBLE ORGANICS

PROCESS	TOTAL SCORE
Granular Media Filtration	280
Micro Screening	251
Ultrafiltration	174

Refer to pages A-32 to A-34 for comparison of processes.

TABLE A-6
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL SUSPENDED SOLIDS AND IMMISCIBLE ORGANICS

SELECTION CRITERIA	WEIGHT	ULTRAFILTRATION	GRANULAR MEDIA FILTRATION	MICROSCREENING
PERFORMANCE				
MOST EFFECTIVE TREATMENT	10	ABLE TO ACHIEVE HIGHEST EFFLUENT QUALITY OF ALL OPTIONS (5) (50)	CAPABLE OF VERY LOW EFFLUENT SUSPENDED SOLIDS < 10 MG/L AND OFTEN < 5 MG/L (3) (30)	CAPABLE OF VERY LOW EFFLUENT SUSPENDED SOLIDS < 10 MG/L BUT GENERALLY NOT LESS THAN 5 MG/L (2) (20)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	NOT AS ENERGY EFFICIENT AS OTHER PROCESSES DUE TO HIGH PRESSURE. MAY REQUIRE PRETREATMENT TO PREVENT PLUGGING PROBLEMS. (3) (6)	VERY EFFICIENT. LOW ENERGY DEMAND. FILTRATE DOES NOT USUALLY REQUIRE FURTHER PROCESSING. (5) (10)	VERY EFFICIENT. LOW ENERGY AND REAGENT DEMANDS. (5) (10)
RESIDUE CHARACTERISTICS	2	REJECT WILL REQUIRE FURTHER TREATMENT (3) (6)	BACKWASH WILL REQUIRE FURTHER TREATMENT (3) (6)	BACKWASH WILL REQUIRE FURTHER TREATMENT (3) (6)
EXTENT USED ELSEWHERE	6	NOT WIDELY USED FOR THIS TYPE OF APPLICATION (1) (6)	MOST WIDELY USED PROCESS FOR THIS TYPE OF APPLICATION (5) (30)	USED LESS OFTEN THAN FILTRATION FOR THIS TYPE OF APPLICATION (3) (18)
SAFETY				
OCCUPATIONAL RISK	10	MODERATE DUE TO HIGH PRESSURE OPERATION (3) (30)	LOW (5) (50)	LOW (5) (50)
ENVIRONMENTAL RISK	10	ALL PROCESSES ARE JUDGED TO BE EQUAL.		
FLEXIBILITY				
WASTE QUANTITIES	7	FLEXIBILITY IS REASONABLY GOOD BUT LOW FLOWS ARE POTENTIALLY A PROBLEM BECAUSE OF NEED FOR HIGH SURFACE SCOUR TO PREVENT MEMBRANE CLOGGING (2) (14)	FLEXIBILITY IS QUITE GOOD. LOWER FLOWS GENERALLY IMPROVE PERFORMANCE (4) (28)	FLEXIBILITY IS QUITE GOOD. LOWER FLOWS GENERALLY IMPROVE PERFORMANCE (4) (28)

TABLE A-6 (CON'T)
COMPARISON OF POLISHING PROCESSES TO REMOVE
RESIDUAL SUSPENDED SOLIDS AND IMMISCIBLE ORGANICS

SELECTION CRITERIA	WEIGHT	ULTRAFILTRATION	GRANULAR MEDIA FILTRATION	MICROSCREENING
FLEXIBILITY (con't)				
WASTE CHARACTERISTICS	7	CHANGE IN TYPE OR CONCENTRATION OF SUSPENDED PARTICLES MAY CAUSE MEMBRANE PLUGGING (2) (14)	RELATIVELY INSENSITIVE. HIGH SOLIDS LOADINGS WILL RESULT IN MORE FREQUENT BACKWASHING (3) (21)	INCREASES IN INFLUENT SUSPENDED SOLIDS ARE REFLECTED IN EFFLUENT BUT PEAKS ARE DAMPENED (2) (14)
RAPID START UP/SHUT DOWN	6	ALL PROCESSES ARE JUDGED TO BE EQUAL		
RELIABILITY				
MAINTENANCE REQUIREMENTS	1	POTENTIALLY HIGH DUE TO TENDANCY FOR MEMBRANE FOULING (1) (1)	MODERATE (3) (3)	MODERATE (3) (3)
SPARE PARTS	2	SPARE MEMBRANES REQUIRED IN ADDITION TO NORMAL PARTS INVENTORY (1) (2)	SPARE MEDIA REQUIRED IN ADDITION TO NORMAL PARTS INVENTORY (3) (6)	STANDARD MECHANICAL SPARES REQUIRED (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	LESS AVAILABLE (2) (6)	READILY AVAILABLE (4) (12)	READILY AVAILABLE (4) (12)
ROBUSTNESS OF EQUIPMENT	1	NOT AS ROBUST AS OTHER PROCESSES (2) (2)	ROBUST (4) (4)	ROBUST (4) (4)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	POTENTIALLY HIGH DUE TO TENDANCY FOR MEMBRANE FOULING (2) (16)	MODERATE TO LOW (4) (32)	MODERATE TO LOW (4) (32)
OPERATIONS				
COMPLEXITY	6	MORE COMPLEX THAN OTHER PROCESSES (2) (12)	RELATIVELY SIMPLE (4) (24)	RELATIVELY SIMPLE (4) (24)
DEGREE OF AUTOMATION	3	ALL PROCESS ARE JUDGED TO BE EQUAL		

TABLE A-6 (CONT'D)
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL SUSPENDED SOLIDS AND IMMISCIBLE ORGANICS

SELECTION CRITERIA	WEIGHT	ULTRAFILTRATION	GRANULAR MEDIA FILTRATION	MICROSCREENING
OPERATIONS (con't)				
START UP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL		
COMMERCIAL & ECONOMIC				
RESTRICTIONS ON USE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL		
COST	7	HIGHER CAPITAL AND OPERATING COSTS THAN OTHER PROCESSES (1) 7)	MODERATE TO LOW CAPITAL AND OPERATING COSTS (3) (21)	MODERATE TO LOW CAPITAL AND OPERATING COSTS (3) (21)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL		
DELIVERY	1	POTENTIALLY LONG DUE TO HIGHER COMPLEXITY OF EQUIPMENT (2) (2)	MODERATE (3) (3)	MODERATE (3) (3)
CANADIAN BENEFITS		ALL PROCESSES ARE JUDGED TO BE EQUAL		
ENGINEERING	1			
SUPPLY AND FABRICATION OF EQUIPMENT	2	ALL PROCESSES ARE JUDGED TO BE EQUAL		
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL		
TOTAL SCORES		174	280	251

TABLE A-7

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

PROCESS	TOTAL SCORE
Carbon Adsorption	426
Ultrafiltration	373
Biological Oxidation	343
Resin Adsorption	319

See pages A-36 to A-40 for comparison of polishing processes for dissolved organics.

TABLE A-7
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

SELECTION CRITERIA	WEIGHT	RESIN ADSORPTION	CARBON ADSORPTION	ULTRAFILTRATION	BIOLOGICAL OXIDATION
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	CAN REMOVE ORGANICS TO LOW LEVELS; RESIN USUALLY EFFECTIVE ONLY FOR SPECIFIC ORGANICS. (3) (30)	WILL REDUCE ORGANICS TO LOW LEVELS. GOOD BROAD RANGE REMOVAL OF ORGANICS. LESS EFFECTIVE ON LOWER MOLECULAR WEIGHT, HIGHLY SOLUBLE ORGANICS. (4) (40)	EFFECTIVE MAINLY FOR LARGE ORGANIC MOLECULES (MOLECULAR WT >1000) AS WELL AS IMMISCIBLE COLLOIDAL SPECIES. (4) (40)	EFFECTIVE ON A WIDE RANGE OF ORGANICS. LESS EFFECTIVE ON TOXIC OR BIOREFRACTORY ORGANICS. (3) (30)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	RESIN REGENERATION REQUIRE SPECIALIZES SOLVENT; STEAM FOR SOLVENT REGENERATION; PRETREATMENT - FILTRATION. POST TREATMENT MAY BE REQ'D. (2) (4)	ENERGY CONSUMPTION IS MINIMAL, SPENT CARBON CAN BE INCINERATED OR SOLIDIFIED FILTRATION IS A NECESSARY PRETREATMENT. POST TREATMENT MAY BE REQUIRED FOR LOW MOLECULAR WEIGHT ORGANICS. (5) (10)	ENERGY USE IS COMPARATIVELY HIGH DUE TO HIGH PRESSURE PROCESS. POST TREATMENT POSSIBLY REQ'D FOR LOW MOLECULAR WEIGHT ORGANICS. (3) (6)	LOW ENERGY USE, SOME SPECIAL REAGENTS I.E. pH ADJUSTMENT OR NUTRIENTS MAY BE REQ'D. PRE OR POST TREATMENT REQUIRED FOR TOXIC AND/OR REFRACTORY ORGANICS. (4) (8)
RESIDUE CHARACTERISTICS	2	ORGANIC SOLVENT FOR REGENERATION. REGENERANT STREAM REQUIRES FURTHER TREATMENT. (2) (4)	SPENT CARBON CAN BE INCINERATED OR SOLIDIFIED. CARBON CAN ALSO BE REGENERATED IF USAGE IS HIGH. (5) (10)	ORGANICS REJECTED IN A CONCENTRATED AQUEOUS WASTE STREAM THAT REQUIRES FURTHER TREATMENT BY INCINERATION OR POSSIBLY SOLIDIFICATION. (3) (6)	SLUDGE USUALLY DEWATERED BEFORE INCINERATION. SLUDGE MAY CONTAIN ADSORBED ORGANICS. SOME VOLATILE ORGANICS WILL BE STRIPPED AS A RESULT OF AERATION PROCESSES. AIR MAY REQUIRE FURTHER TREATMENT. (4) (8)
EXTENT USED ELSEWHERE	6	USED FOR PHENOL REMOVAL; OTHER OPERATING AREAS HAVE LIMITED EXPERIENCE. (2) (12)	CARBON ADSORPTION IS WIDELY USED IN EFFLUENT TREATMENT INVOLVING REMOVAL OF TOXIC ORGANICS. (5) (30)	NEW, BUT ACCEPTED, TECHNOLOGY; NOT AS WIDELY USED AS THE OTHERS. (3) (18)	WIDELY USED FOR CONTINUOUS AND CONSISTANT FEEDS; NOT FOR VARIABLE INDUSTRIAL WASTES. (3) (18)
SAFETY					
OCCUPATIONAL RISK	10	REGENERATING SOLVENT MAY BE HAZARDOUS IF THE OPERATORS COME IN CONTACT WITH IT. SOLVENTS MAY BE FLAMMABLE; HOWEVER PROCEDURES ARE WELL ESTABLISHED IN THIS AREA. (3) (30)	HAZARD IS LOW. NEED PROPER VESSEL ENTRY PROCEDURES TO ENTER TOWER SINCE OXYGEN LEVELS MAY BE LOW. OPERATION IS COMPLETELY ENCLOSED. (5) (50)	MODERATE TO LOW DUE TO HIGH PRESSURE OPERATION. (4) (40)	LOW. SOME POTENTIAL HAZARD DUE TO ORGANICS PRESENT IN AERATION AIR. (5) (50)

TABLE A-7 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

SELECTION CRITERIA	WEIGHT	RESIN ADSORPTION	CARBON ADSORPTION	ULTRAFILTRATION	BIOLOGICAL OXIDATION
SAFETY (con't)					
ENVIRONMENTAL RISK	10	LOW RISK. EFFLUENT CAN BE TESTED. RETREATMENT WOULD BE EFFECTIVE. (5) (50)	LOW RISK. EFFLUENT CAN BE TESTED. RETREATMENT WOULD BE EFFECTIVE PROVIDED FRESH CARBON IS AVAILABLE. (5) (50)	LOW RISK. EFFLUENT CAN BE TESTED. RETREATMENT WOULD BE EFFECTIVE. (5) (50)	MODERATE RISK. RETREATMENT WOULD BE LESS EFFECTIVE COMPARED TO OTHER METHODS PARTICULARLY WHERE TOXIC OR REFRACTORY ORGANICS ARE PRESENT. (4) (40)
FLEXIBILITY					
WASTE QUANTITIES	7	FEED CAN BE VARIED BETWEEN <30% AND 100% OF DESIGN, CHANNELING CAN BE A PROBLEM. (4) 28)	FEED RATE CAN BE VARIED FROM 20% TO 100%. (5) (35)	FEED RATE CAN BE VARIED FROM 30% TO 100% OF DESIGN. (4) (28)	FEED RATE CAN BE VARIED SOMEWHAT DEPENDING ON PROCESS USED BUT GENERALLY MORE SUSCEPTIBLE TO HYDRAULIC OVERLOAD THAN OTHER PROCESSES. (3) (21)
WASTE CHARACTERISTICS	7	FEED COMPOSITION CAN VARY FROM NO ORGANICS TO 2% ORGANICS; AT HIGH ORGANIC LOADINGS A SECOND RESIN ADSORPTION STAGE MAY BE REQUIRED. (4) (28)	CAN TREAT VARYING FEED COMPOSITION WITH GOOD REMOVAL EFFICIENCY. HIGHER ORGANIC LOAD WILL INCREASE CARBON CONSUMPTION. (4) (28)	VERY LITTLE EFFECT, WASTE STREAM FLOW RATE MAY REQUIRE ADJUSTMENT; CAN HANDLE UP TO 2% SUSPENDED SOLIDS. (4) (28)	FEED COMPOSITION MUST BE KEPT RELATIVELY CONSTANT TO AVOID SHOCK LOADING. (1) (7)
RAPID START UP/SHUT DOWN	6	FEED RATE CAN BE STOPPED AND STARTED AS REQUIRED. (5) (30)	CAN BE STARTED UP OR SHUT DOWN EASILY AND QUICKLY. (5) (30)	START-UP AND SHUTDOWN CAN BE DONE QUICKLY AND EASILY. (5 (30)	LESS SUITED TO START/STOP OPERATION PARTICULARLY WHERE LONG SHUTDOWNS ARE INVOLVED. (3) (18)
RELIABILITY					
MAINTENANCE REQUIREMENTS	1	REGENERATION PROCESS WILL REQUIRE EQUIPMENT CLEANING, PUMP MAINTENANCE, INSTRUMENTATION SERVICE; ALSO RESIN MUST BE REPLACED PERIODICALLY. (4) (4)	REPLACING CARBON WILL BE THE ONLY REGULAR ACTIVITY. HIGH ORGANIC LOADING WILL REQUIRE FREQUENT CARBON REPLACEMENT. (3) (3)	MEMBRANE MUST BE CHANGED BUT MAY LAST YEARS; OTHER PROBLEMS TYPICAL OF ALL PROCESSES. (4) (4)	CLARIFIER, AERATORS AND SLUDGE REMOVAL EQUIPMENT WILL NEED NORMAL MAINTENANCE, SYSTEMS WILL NOT GENERALLY REQUIRE MUCH MAINTENANCE UNLESS FREQUENT UPSETS OCCUR. (4) (4)

TABLE A-7 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

SELECTION CRITERIA	WEIGHT	RESIN ADSORPTION	CARBON ADSORPTION	ULTRAFILTRATION	BIOLOGICAL OXIDATION
RELIABILITY (con't)					
SPARE PARTS	2	SPARE RESIN AND SOLVENT REQUIRED IN ADDITION TO USUAL SPARE PARTS (3) (6)	NO UNUSUAL EQUIPMENT SPARES REQUIRED. (4) (8)	SPARE MEMBRANES REQ'D. IN ADDITION TO USUAL SPARE PARTS (3) (6)	NO UNUSUAL SPARES REQUIRED. (4) (8)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	RESIN AND REGENERATING SOLVENT ARE SPECIALIZED AND MAY BE DIFFICULT TO OBTAIN ON SHORT NOTICE. (3) (9)	CARBON AND EQUIPMENT READILY AVAILABLE FROM SUPPLIERS ON SHORT NOTICE. (5) (15)	MEMBRANES MAY BE LONG DELIVERY. (3) (9)	SPARES AND REAGENTS READILY AVAILABLE ON SHORT NOTICE. (5) (15)
ROBUSTNESS OF EQUIPMENT	1	EQUIPMENT IS ROBUST BUT RESIN CAN BE PHYSICALLY OR CHEMICALLY DAMAGED. (4) (4)	EQUIPMENT AND CARBON ARE COMPARATIVELY ROBUST (5) (5)	EQUIPMENT IS ROBUST BUT MEMBRANES ARE SUBJECT TO DAMAGE. (4) (4)	EQUIPMENT IS ROBUST BUT BIOLOGICAL MASS IS PRONE TO UPSET. (5) (5)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	RESIN IS ORGANIC AND CERTAIN ORGANIC SOLVENTS CAN DAMAGE IT; STRONG OXIDANTS CAN ALSO DAMAGE IT; CERTAIN ORGANICS MAY NOT BE ADSORBED. (2) (16)	A LARGE INCREASE IN ORGANIC CONTENT IN THE FEED COULD CAUSE BREAKTHROUGH OR NECESSITATE EARLY CARBON REPLACEMENT. (4) (32)	UPSETS HAVE LITTLE EFFECT. SOME FLOW RATE ADJUSTMENT MAY BE REQUIRED. (3) (24)	PROCESS SUBJECT TO UPSET; DAYS OR WEEKS MAY BE REQUIRED TO RE-ESTABLISH NORMAL OPERATIONS AFTER A MAJOR UPSET. (1) (8)
OPERATIONS					
COMPLEXITY	6	PROCESS WILL BE COMPARATIVELY COMPLEX DUE TO NEED FOR RESIN REGENERATION SYSTEM. (3) (18)	EQUIPMENT IS RELATIVELY SIMPLE. (5) (30)	EQUIPMENT IS MORE COMPLEX THAN ACTIVATED CARBON OR BIOLOGICAL OXIDATION. (4) (24)	EQUIPMENT IS SIMPLE. (5) (30)
DEGREE OF AUTOMATION	3	PROCESS CAN BE AUTOMATED. OPERATOR CAN CONTROL EFFLUENT QUALITY BY FREQUENCY OF REGENERATION. (5) (15)	OPERATION IS EASILY CONTROLLED. TWO TOWER SYSTEM ENABLES OPERATOR TO DETECT SPENT CARBON BEFORE BREAKTHROUGH. EFFLUENT QUALITY CAN BE CONTROLLED BY FREQUENCY OF CARBON REPLACEMENT. (5) (15)	PROCESS CAN BE AUTOMATED. EFFLUENT QUALITY CAN BE CONTROLLED TO SOME EXTENT BY VARYING PROCESS CONTROLS. (5) (15)	PROBLEMS WITH VARYING FEED RATES OR COMPOSITION WILL REQUIRE CLOSE OPERATOR ATTENTION. SOME CONTROL OF EFFLUENT QUALITY IS POSSIBLE BY VARYING PROCESS CONTROLS. (4) (12)

TABLE A-7 (CONT'D)
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

SELECTION CRITERIA	WEIGHT	RESIN ADSORPTION	CARBON ADSORPTION	ULTRAFILTRATION	BIOLOGICAL OXIDATION
OPERATIONS (con't)					
START UP ASSISTANCE	1	TRAINING WILL BE QUITE EXTENSIVE DUE TO ADDITIONAL REGENERATION STEP. TESTING PROCEDURES REQUIRED AS WELL. OPERATING ASSISTANCE (START-UP) WILL BE REQ'D AND WILL BE AVAILABLE. (3) (3)	NORMAL TRAINING REQUIRED-ASSISTANCE READILY AVAILABLE. (5) (5)	NORMAL TRAINING REQUIRED-ASSISTANCE READILY AVAILABLE. (5) (5)	TRAINING REQUIRED WILL BE EXTENSIVE IN ORDER TO AVOID OPERATING PROBLEMS. (3) (3)
COMMERCIAL & ECONOMIC					
RESTRICTION ON USE	1	LICENCE FEE MAY APPLY TO RESIN AND FOR REGENERATING SOLVENT. (3) (3)	N/A (5) (5)	N/A (5) (5)	N/A (5) (5)
COST	7	CAPITAL COST IS EXPECTED TO BE HIGHER THAN OTHER OPTIONS DUE TO NEED FOR SOLVENT REGENERATION EQUIPMENT. OPERATING COSTS WILL BE MODERATE TO HIGH DEPENDING ON SOLVENT MAKE UP REQUIREMENTS. (2) (14)	MODERATE CAPITAL COSTS. MODERATE TO HIGH OPERATING COST DEPENDING ON FREQUENCY OF CARBON REPLACEMENT. (2) (14)	MODERATE CAPITAL COST. MODERATE TO LOW OPERATING COST DEPENDING ON FREQUENCY OF MEMBRANE REPLACEMENT. (3) (21)	LOW CAPITAL AND OPERATIANG COSTS. (5) (35)
SUPPLIER COMPETITION AN RELIABILITY	1		ALL PROCESSES ARE JUDGED TO BE EQUAL		
DELIVERY	1	RESIN AND REGENERATING SOLVENT MAY BE LONG DELIVERY. (2) (2)	NORMAL DELIVERY (3) (3)	MEMBRANES MAY BE LONG DELIVERY DEPENDING ON TYPE REQUIRED. (2) (2)	NORMAL DELIVERY (3) (3)
CANADIAN BENEFITS					
ENGINEERING	1	DETAILED ENGINEERING CAN BE DONE IN ONTARIO. PROCESS DEVELOPMENT HAS BEEN DONE AND PATENTS WILL, MOST LIKELY, APPLY. (3) (3)	LITTLE REQUIRED. UNITS CAN BE PURCHASED AS A PACKAGE. (2) (2)	VERY LITTLE, UNIT IS PURCHASED AS A PACKAGE. (2)(2)	ALL FROM WITHIN ONTARIO OR CANADA. (5) (5)

TABLE A-7 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED ORGANICS

SELECTION CRITERIA	WEIGHT	RESIN ADSORPTION	CARBON ADSORPTION	ULTRAFILTRATION	BIOLOGICAL OXIDATION
SUPPLY AND FABRICATION OF EQUIPMENT	2	MOST OF THE EQUIPMENT CAN BE FABRICATED LOCALLY; RESIN FROM FOREIGN SUPPLIER; REGENERATING SOLVENT FROM CANADIAN SUPPLIER. (3) (6)	EQUIPMENT CAN BE FABRICATED IN ONTARIO, CARBON WILL BE IMPORTED. (3) (6)	POTENTIALLY CANADIAN. MANUFACTURE, ALTHOUGH MEMBRANES GENERALLY COME FROM U.S. (3) (6)	ALL FROM WITHIN ONTARIO OR CANADA. (5) (10)
LONG TERM TECHNOLOGY TRANSFER	2		ALL PROCESSES ARE JUDGED TO BE EQUAL		
TOTAL SCORES		319	426	373	343

TABLE A-8

SUMMARY OF TOTAL SCORES FOR ALTERNATIVE POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

PROCESS	TOTAL SCORE
Reverse Osmosis	349
Evaporation	319
Ion Exchange	309
Electrodialysis	267
Liquid Ion Exchange	182

See pages A-42 to A-46 for comparison of polishing processes for dissolved inorganics.

TABLE A-8
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

SELECTION CRITERIA	WEIGHT	LIQUID ION EXCHANGE	ELECTRODIALYSIS	EVAPORATION	ION EXCHANGE	REVERSE OSMOSIS
PERFORMANCE						
MOST EFFECTIVE TREATMENT	10	DOES NOT REMOVE BROAD RANGE OF INORGANICS. ION EXCHANGE SOLVENTS ARE SELECTIVE BY DESIGN. (1) (10)	ONLY SUITABLE FOR TDS CONCENTRATIONS RANGING UP TO 0.5WT% (1) (10)	CAN TREAT A BROAD RANGE OF INORGANICS AND AT HIGH CONCENTRATIONS (>10 WT%). WILL YIELD A PURE CONDENSATE STREAM TO BE RELEASED TO THE ENVIRONMENT, AND A CONCENTRATED STREAM TO BE SOLIDIFIED. MOST ORGANICS WILL REPORT TO VAPOUR PHASE HOWEVER. (5) (50)	ONLY CAPABLE OF HANDLING 1 TO 2% TDS MAXIMUM. LEVELS ARE MUCH LOWER (APPROXIMATELY 0.5WT%) FOR EFFICIENT OPERATION. (1) (10)	CAPABLE OF HANDLING TDS CONCENTRATIONS OF UP TO 4 WT% SOMETIMES MORE. WILL ALSO REMOVE A WIDE RANGE OF ORGANICS WITH PROPER MEMBRANE. (3) (30)
EFFICIENCY: ENERGY UTILITIES, REAGENTS, ETC.	2	USE WOULD LIKELY REQUIRE SEVERAL DIFFERENT ION EXCHANGE SPECIES AND/OR SOLVENTS; SOLVENT PURIFICATION WILL BE ENERGY INTENSIVE AND/OR A COMPLEX PROCESS. ORGANIC REMOVAL WILL BE A NECESSARY POST-TREATMENT. (1) (2)	HIGH ELECTRIC POWER CONSUMPTION; FEED SHOULD BE ACIDIFIED; ANTI-SCALING REAGENTS MAY BE REQUIRED. (2) (4)	ENERGY CONSUMPTION IS VERY HIGH; HOWEVER STEAM FROM THE INCINERATOR MAY BE AVAILABLE AND CONDENSING ACHIEVED BY AIR COOLERS; pH ADJUSTMENT AND ANTI-SCALING/ANTI-FOULANTS MAY BE REQUIRED. (2) (4)	LOW ENERGY NEEDS, BUT STRONG ACID AND BASE USED, EFFLUENT WOULD LIKELY REQUIRE FURTHER TREATMENT FOR REUSE. (3) (6)	ENERGY REQUIREMENTS ARE MODERATE. REAGENTS REQ'D FOR CLEANING AND POSSIBLY ANTI-SCALING. NO POST PROCESSING REQUIRED FOR REUSE. (4) (8)
RESIDUE CHARACTERISTICS	2	POLLUTANTS FROM RECOVERY SECTION WILL REQUIRE FURTHER TREATMENT; PERHAPS, IN A SOPHISTICATED AND COMPLEX PROCESS. (3) (6)	TWO WASTE STREAMS PRODUCED; BOTH MAY REQUIRE FURTHER TREATMENT. SOME GASES MAY BE PRODUCED. (2) (4)	CONCENTRATED WASTE STREAM TO SOLIDIFICATION; HOWEVER OTHER TREATMENT, I.E. PRECIPITATION, POSSIBLE. CONDENSATE IS SUITABLE FOR REUSE. (4) (8)	WASTE STREAMS; STRONG ACID AND BASE FROM REGENERATION. WILL REQUIRE FURTHER TREATMENT (3) (6)	CONCENTRATED REJECTS WILL REQUIRE SOLIDIFICATION. PERMEATE IS SUITABLE FOR REUSE. (4) (8)
EXTENT USED ELSEWHERE	6	USED ONLY FOR SPECIALIZED APPLICATIONS IN INDUSTRY; NOT WIDELY USED FOR WASTE TREATMENT. (1) (6)	NOT WIDELY USED FOR WASTE TREATMENT. (2) (12)	TECHNOLOGY IS WELL PROVEN BUT NOT WIDELY USED IN WASTE TREATMENT BECAUSE OF HIGH COST. (3) (18)	PROVEN IN INDUSTRY; BUT LIMITED WASTE TREATMENT APPLICATIONS. (3) (18)	PROVEN IN INDUSTRIAL AND MUNICIPAL APPLICATIONS; WASTE TREATMENT APPLICATIONS ARE INCREASING. (4) (24)

TABLE A-8 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

SELECTION CRITERIA	WEIGHT	LIQUID ION EXCHANGE	ELECTRODIALYSIS	EVAPORATION	ION EXCHANGE	REVERSE OSMOSIS
SAFETY						
OCCUPATIONAL RISK	10	COMPLEX PROCESS MAY INVOLVE SOME HAZARDS. ORGANIC ION EXCHANGE SPECIES AND SOLVENTS MAY BE HAZARDOUS, I.E. FLAMMABILITY. (3) (30)	GASES PRODUCED MAY BE NOXIOUS; HIGH VOLTAGE POSES SOME HAZARD. (3) (30)	ELEVATED TEMPERATURES AND PRESSURES POSE SOME HAZARD. (3) (30)	ACID AND BASE HAZARDOUS, NORMAL OPERATION IS NOT HAZARDOUS. OPERATION IS COMPLETELY ENCLOSED. (3) (30)	MODERATE RISK DUE TO HIGH PRESSURE OPERATION. (3) (30)
ENVIRONMENTAL RISK	10	ORGANIC RELEASE IS POSSIBLE BUT CAN BE RESTRICTED. (3) (30)	EFFLUENT CAN BE RETAINED AND TESTED BEFORE RELEASE. (4) (40)	UPSET COULD CAUSE RELEASE TO ATMOSPHERE SINCE GASEOUS EFFLUENT CAN NOT BE RETAINED AND TESTED BEFORE RELEASE. (2) (20)	RELEASE OF CONTAMINANTS HIGHLY UNLIKELY BECAUSE EFFLUENT CAN BE RETAINED AND TESTED BEFORE RELEASE. (4) (40)	RELEASE OF CONTAMINANTS HIGHLY UNLIKELY BECAUSE EFFLUENT CAN BE RETAINED AND TESTED BEFORE RELEASE. (4) (40)
FLEXIBILITY						
WASTE QUANTITIES	7	PROCESS MUST BE REGULATED TO MAINTAIN EFFICIENCY AS FEED RATE CHANGES. (1) (7)	FLOW RATE CAN BE VARIED FROM 20% TO 100%; POWER CONSUMPTION MAY BECOME PROHIBITIVELY HIGH AT LOW RATES, NECESSITATING RECYCLE OF CONCENTRATED ELECTROLYTES. (2) (14)	SYSTEM DOES NOT RESPOND QUICKLY TO CHANGES IN FEED RATE; HOWEVER FEED AND EFFLUENT TANKS, AND RECYCLE FACILITIES WILL MINIMIZE THIS LIMITATION (3) (21)	CAN BE VARIED BETWEEN 30% AND 100% OF DESIGN, START-UP AND SHUTDOWN QUICK AND EASY. (3) (21)	CAN BE VARIED 30% TO 100% OF DESIGN. (3) (21)
WASTE CHARACTERISTICS	7	PROCESS MUST BE REGULATED TO MAINTAIN EFFICIENCY AS FEED COMPOSITION CHANGES. NOT SUITABLE FOR REDUCTION OF TDS IN GENERAL. (1) (7)	RELATIVELY SENSITIVE SINCE PROCESS CAN ONLY HANDLE TDS CONCENTRATIONS OF UP TO ABOUT 0.5 WT%. (3) (21)	RELATIVELY INSENSITIVE EXCEPT WHERE SCALE FORMING COMPONENTS ARE PRESENT. CAN USUALLY HANDLE TDS CONCENTRATIONS OF 10 WT% OR MORE. (5) (35)	HIGH LOADINGS CAUSE PREMATURE BREAKTHROUGH; MAXIMUM CONCENTRATION OF TDS IS 2 WT%. (3) (21)	RELATIVELY INSENSITIVE. CAN HANDLE TDS CONCENTRATIONS OF 4 WT% OR MORE IN SOME CASES. (4) (28)
RAPID START UP/SHUT DOWN	6	START-UP AND SHUTDOWN COULD BE RELATIVELY COMPLICATED BECAUSE OF NEED FOR REGENERATION LOOP. (1) (6)	CAN BE STARTED UP AND SHUT DOWN RELATIVELY QUICKLY. (4) (24)	WILL TAKE 2 HOURS MINIMUM TO START UP AND 1-1/2 HOURS MINIMUM TO SHUT DOWN. (2) (12)	START-UP AND SHUTDOWN IS RELATIVELY QUICK AND EASY; RECYCLE IS REQ'D. (4) (24)	START-UP AND SHUTDOWN IS RELATIVELY QUICK AND EASY. (4) (24)

TABLE A-8 (CONT'D)
COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

SELECTION CRITERIA	WEIGHT	LIQUID ION EXCHANGE	ELECTRODIALYSIS	EVAPORATION	ION EXCHANGE	REVERSE OSMOSIS
RELIABILITY						
MAINTENANCE REQUIREMENTS	1	PROCESS WILL REQUIRE CONSIDERABLE MAINTENANCE BECAUSE OF THE NUMEROUS PIECES OF EQUIPMENT I.E. PUMPS, EXCHANGERS, SEPARATORS, ETC. (2) (2)	MEMBRANE REPLACEMENT; SYSTEM HAS TWO, PERHAPS THREE, MEMBRANES MAY REQUIRE CHEMICAL CLEANING; ELECTRODES MAY REQUIRE CLEANING OR SCRAPING. (3) (3)	CORROSION AND SCALING PROBLEMS ARE POSSIBLE; EQUIPMENT CLEANING I.E. HEAT EXCHANGERS, PUMP REPAIRS; SYSTEM WILL INVOLVE MANY PIECES OF EQUIPMENT THEREFORE MAINTENANCE COULD BE HIGH. (3) (3)	RESIN REPLACEMENT WILL BE REQ'D PERIODICALLY OTHERWISE MAINTENANCE IS RELATIVELY LOW. (4) (4)	MEMBRANES REQUIRE REGULAR CLEANING AND PERIODIC REPLACEMENT. (3) (3)
SPARE PARTS	2	SPARES WILL BE COMMON TO OTHER PROCESSES; SOME MAY BE OF SPECIAL ALLOYS. (4) (8)	SPARE MEMBRANES AND ELECTRODES MAY BE REQUIRED; PARTS FOR RECTIFIER (DC SUPPLY) MAY BE REQUIRED. (3) (6)	SPARES WILL BE THE SAME AS FOR OTHER PROCESSES (I.E. MAINLY PUMP PARTS). (4) (8)	SPARE RESIN WILL BE REQUIRED IN ADDITION TO NORMAL SPARES. (3) (6)	SPARE MEMBRANES WILL BE REQUIRED IN ADDITION TO NORMAL SPARES. (3) (6)
AVAILABILITY OF SPARE PARTS AND REAGENTS	3	REAGENTS, I.E. ION EXCHANGE SPECIES WILL REQUIRE DEVELOPMENT AND MAY BE DIFFICULT TO FIND. (2) (6)	MEMBRANES AND ELECTRODES MAY BE LONG DELIVERY ITEMS. (3) (9)	READILY AVAILABLE. (4) (12)	RESINS ARE READILY AVAILABLE; ACID AND BASE ARE READILY AVAILABLE. (4) (12)	MEMBRANES READILY AVAILABLE BUT POSSIBLY LONG DELIVERY. (3) (9)
ROBUSTNESS OF EQUIPMENT	1	REGENERATION STEP(S) MAY ADVERSELY AFFECT THE ION EXCHANGE SPECIES. EQUIPMENT IS ROBUST. (4) (4)	MEMBRANES MAY BE DAMAGED. (3) (3)	EQUIPMENT IS ROBUST. (5) (5)	RESIN DAMAGE POSSIBLE BUT EQUIPMENT IS ROBUST. (4) (4)	MEMBRANE DAMAGE POSSIBLE. (3)(3)
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	PROCESS MAY NOT EASILY RECOVER FROM UPSETS DUE TO CONTAMINANT SPECIFIC NATURE OF THE SOLVENTS. (1) (8)	UPSET WILL CAUSE CHANGE IN EFFLUENT QUALITY; LOSS OF FEED COULD CAUSE ELECTRODE DAMAGE. THIS WILL OCCUR OVER A RELATIVELY SHORT PERIOD OF TIME.. (2) (16)	NOT PARTICULARLY VULNERABLE TO UPSETS. EQUIPMENT FOULING FOR EXAMPLE WILL CAUSE GRADUAL DECREASE IN PERFORMANCE. (4) (32)	UPSET COULD CAUSE BREAKTHROUGH. THIS WOULD OCCUR OVER A RELATIVELY SHORT PERIOD OF TIME. (3) (24)	PROBLEMS WITH MEMBRANES WILL CAUSE GRADUAL WORSENING OF FLUX RATES AND/OR PRODUCT QUALITY. (4) (32)

TABLE A-8 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

SELECTION CRITERIA	WEIGHT	LIQUID ION EXCHANGE	ELECTRODIALYSIS	EVAPORATION	ION EXCHANGE	REVERSE OSMOSIS
OPERATIONS COMPLEXITY OF PROCESS AND EQUIPMENT	6	PROCESS IS VERY COMPLEX AND INCORPORATES NUMEROUS PIECES OF SOPHISTICATED EQUIPMENT. (2) (12)	OPERATION IS SIMPLE BUT CAREFUL CONTROL OF THE OPERATION IS NECESSARY; EQUIPMENT IS QUITE COMPLEX. (3) (18)	PROCESS WILL INCLUDE MANY PIECES OF EQUIPMENT RESULTING IN RELATIVELY COMPLEX SYSTEM. (3) (18)	NORMAL OPERATION IS RELATIVELY SIMPLE. (4) (24)	OPERATION AND SYSTEM IS RELATIVELY SIMPLE. (4) (24)
DEGREE OF AUTOMATION	3	AUTOMATION WILL BE COMPLEX BUT WILL REDUCE OPERATOR ATTENTION; OPERATOR WILL HAVE LITTLE CONTROL OVER EFFLUENT QUALITY. (2) (6)	AUTOMATION IS RELATIVELY SIMPLE; OPERATOR CONTROL OF EFFLUENT QUALITY IS LIMITED. (3) (9)	TO PROVIDE FOR THE VARIATION IN FEED RATES AND COMPOSITIONS, AUTOMATED CONTROL SYSTEM WILL BE QUITE COMPLEX. (3) (9)	NORMAL OPERATION WILL BE SIMPLE, REGENERATION COMPLEX BUT MANAGEABLE. (4) (12)	SIMPLE AUTOMATION FEASIBLE. CONTROL OF DISCHARGE QUALITY CAN BE ACHIEVED BY VARYING PROCESS CONDITIONS. (4) (12)
START UP ASSISTANCE	1	TRAINING AND ASSISTANCE REQ'D WILL BE HIGH DUE TO COMPLEX SYSTEM. (1) (1)	START-UP ASSISTANCE WILL BE MINIMAL; TRAINING WILL BE EXTENSIVE ESPECIALLY OF MAINTENANCE PEOPLE. (3) (3)	COMPLEX SYSTEM, TRAINING AND ASSISTANCE REQ'D DURING START-UP READILY AVAILABLE. (3) (3)	REGENERATION REQUIRES EXTENSIVE TRAINING AND START-UP ASSISTANCE. TRAINING READILY AVAILABLE. (3) (3)	TECHNOLOGY IS COMPLEX, OPERATOR TRAINING EXTENSIVE BUT READILY AVAILABLE. (3) (3)
COMMERCIAL & ECONOMIC RESTRICTIONS ON USE	1	POSSIBLE FEE ASSOCIATED WITH USING PROPRIETARY ION EXCHANGE SPECIES. (2) (2)	NOT USUALLY APPLICABLE. (5) (5)	N/A (5) (5)	N/A (5) (5)	N/A (5) (5)
COST	7	HIGH CAPITAL AND OPERATING (1) (7)	MODERATE CAPITAL AND OPERATING (3) (21)	HIGH CAPITAL AND OPERATING (1) (7)	MODERATE CAPITAL AND OPERATING (3) (21)	MODERATE CAPITAL AND OPERATING (3) (21)
SUPPLIER COMPETITION AND RELIABILITY	1	MAY BE LIMITED DUE TO SPECIALIZED NATURE OF PROCESS. (2) (2)	ADEQUATE. (3) (3)	ADEQUATE. (3) (3)	ADEQUATE. (3) (3)	ADEQUATE. (3) (3)

TABLE A-8 (CONT'D)

COMPARISON OF POLISHING PROCESSES TO REMOVE RESIDUAL DISSOLVED INORGANICS

SELECTION CRITERIA	WEIGHT	LIQUID ION EXCHANGE	ELECTRODIALYSIS	EVAPORATION	ION EXCHANGE	REVERSE OSMOSIS
COMMERCIAL & ECONOMIC (con't)						
DELIVERY	1	LONG DELIVERY ON ION EXCHANGE SPECIES AND PERHAPS ON SOME SPECIALIZED SPARE PARTS. (2) (2)	EQUIPMENT MAY BE LONG DELIVERY. (2) (2)	AVERAGE FOR SPARE PARTS AND CHEMICALS. EQUIPMENT WILL BE LONG DELIVERY. (2) (2)	MODERATE (3) (3)	MODERATE (3) (3)
CANADIAN BENEFITS						
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL				
SUPPLY AND FABRICATION OF EQUIPMENT	2	CAN BE DONE LOCALLY. (5) (10)	LIMITED AMOUNT OF EQUIPMENT WILL BE FROM CANADA. (3) (6)	ALL FROM WITHIN ONTARIO. (5) (10)	EQUIPMENT MOSTLY FROM CANADA, RESIN FROM OUTSIDE. (3) (6)	EQUIPMENT FROM CANADA. MEMBRANES FROM U.S. (3) (6)
LONG TERM TECHNOLOGY TRANSFER	2	TECHNOLOGY AND EXPERIENCE COULD BE MARKETED. (4) (8)	PATENTS BY OTHERS WILL COVER THIS TECHNOLOGY; OPERATING HISTORY MAY BE MARKETABLE. (2) (4)	PROCESS TECHNOLOGY IS WELL DEVELOPED; EXPERIENCE CAN PERHAPS BE MARKETED. (2) (4)	TECHNOLOGY PURCHASED, LITTLE FURTHER DEVELOPMENT POSSIBLE; EXPERIENCE MARKETABLE. (3) (6)	EXPERIENCE COULD BE MARKETABLE. (3) (6)
TOTAL SCORES		182	267	319	309	349

APPENDIX B
ADDITIONAL TREATABILITY DATA

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS(2)	TREATABILITY
A. METALS		
Antimony	o Precip/Coag.	- 28 to 65% reduction @ 600 ug/L with alum,lime, ferric chloride coagulants
Arsenic	o Precip/Coag.	- 76-90% reduction @ 5 mg/L with ferric sulphate and lime as coagulants
	o Carbon Ads.	- no reduction @1.1 ug/L
	o Misc. Sorbents	- 96% reduction @ 25 mg/L with silicon alloy adsorbent
Arsenic (+5)	o Precip/Coag.	- 94-97% reduction @ 21-25 mg/L with alum and lime coagulant
Beryllium	o Precip/Coag.	- 98-99% reduction @ 100 ug/L with alum, lime and ferric chloride
Cadmium	o Bio. Treatment	- Inhibitory @ 1-10 mg/L
	o Precip/Coag.	- 45-98% reduction @ 9 ug/L - 5 mg/L with lime ferric chloride and ferric sulphate
	o Rev. Osmosis	- 90-99% reduction @ 0.1 - 1.0 mg/L
	o Carbon Ads.	- 6-37% reduction @ 1.8 - 29 ug/L
	o Misc. Sorbents	- 96% reduction @ 25 mg/L with silicon alloy adsorbent

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(1) Source: Shuckrow et al[24]
Refer to p. 183 in text for explanation of table
ug/l = micrograms per liter.

(2) For Abbreviations, see page B-17.

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
A. **METALS** (Cont'd)		
Chromium	o Biol. Treatment	- 27-28% reduction @ 0.8 - 4 mg/L
	o Precip/Coag.	- 27-54% reduction @ 0.1 - 5 mg/L with lime
	o Rev. Osmosis	- 85-98% reduction @ 1 - 12 mg/L
	o Carbon Ads.	- 37-43% reduction @ 41-84 ug/L
	o Misc. Sorbents	- 100% reduction @ 300 mg/L with high clay soil adsorbent
Copper	o Bio. Treatment	- 7-77% reduction @ 0.2 - 20 mg/L; reported to be inhibitory @ >0.5 mg/L
	o Precip/Coag.	- 67-98% reduction @ 0.2 - 15 mg/L with alum, lime, ferric sulphate coagulants
	o Rev. Osmosis	- 95-100% reduction @ 0.6-12 mg/L
	o Ultra Filt.	- 82% reduction @ 0.44 mg/L
	o Carbon Ads.	- 8-96% reduction @ 0.05-100 mg/L
	o Misc. Sorbents	- 96-100% reduction @ 300 mg/L with silicon alloy and high clay soil adsorbents
Iron	o Bio. Treatment	- 62% reduction @ 0.6 mg/L soluble iron
	o Precip/Coag.	- 26-99% reduction @ 0.2-10 mg/L with lime & ferric chloride coag.
	o Rev. Osmosis	- 100% reduction @ 12 mg/L
	o Ultra Filt.	- 85% reduction @ 6.8 mg/L
	o Carbon Ads.	- 45-68% reduction @ 40-207 ug/L @ 0.9-12 mg/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
A. **METALS** (Cont'd)		
Lead	o Bio. Treatment	- Inhibitory @ <10 mg/L
	o Precip/Coag.	- 43-99% reduction @ 0.02-5 mg/L with lime, ferric sulfate, & alum coagulants
	o Rev. Osmosis	- 98-100% reduction
	o Ultra Filt.	- Foam fractionation with sodium dodecylbenzene sulfate
	o Carbon Ads.	- 13-93% reduction @ 100 mg/L; no reduction @ 5-22 ug/L
	o Misc. Sorbents	- 96% reduction with silicon alloy adsorbent; redwood bark also tried
Mercury	o Bio. Treatment	- Conflicting data; 51-58% reduction @ 5-10 mg/L & inhibitory @ any concentration
	o Precip/Coag.	- 25-98% reduction @ 0.001-5 mg/L with lime & ferric chloride coag.
	o Solv. Extraction	- 99% reduction @ 2 mg/L with high molecular weight amines & quartenary salts
	o Carbon Ads.	- 80-99% reduction @ 0.001-100 mg/L with GAC & PAC plus chelating agent - Misc. Sorbents
Nickel	o Bio. Treatment	- 0-42% reduction @ 0.3-20 mg/L
	o Precip/Coag.	- 10-100% reduction @ 0.9-5 mg/L with alum, lime, & ferric sulfate
	o Rev. Osmosis	- 93-97% reduction @ 12 mg/L
	o Carbon Ads.	- 4-52% reduction @ 100 mg/L
Selenium	o Precip/Coag.	- 0-80% reduction @ 0.002-100 mg/L with lime, alum, & ferric chloride coagulants
	o Carbon Ads.	- 96% reduction @ 500 mg/L after GAC & lime precip.

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
A. **METALS** (Cont'd)		
Silver	o Precip/Coag.	- 38-98% reduction @ 0.006-500 mg/L with lime, alum, & ferric chloride coagulants
Thallium	o Precip/Coag.	- 30-60% reduction @ 500 ug/L with lime, alum, & ferric chloride coag.
	o Carbon Ads.	- 84% reduction after GAC & lime precipitation
Zinc	o Bio. Treatment	- Reported to be inhibitory @ 0.08-1 mg/L; also 13-91% reduction reported @ 0.3-10 mg/L
	o Precip/Coag.	- 1% reduction with alum; 37-100% reduction @ 0.3-5 mg/L with lime & ferric chloride coag.
	o Rev. Osmosis	- 97-100% reduction @ 9-32 mg/L
	o Ultra Filt.	- 79% reduction @ 1.8 mg/L
	o Carbon Ads.	- 61-81% reduction @ 0.4-0.6 mg/L
	o Misc. Sorbents	- 99% reduction @ 10 mg/L with silicon oxide & calcium oxide slags as absorbents
B. **HALOCARBONS**		
Bromodichloromethane	o Stripping	- Air & steam strippable
	o Solvent Ext.	- Soluble in most organics
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed @ 2 mg/L
Bromoform	o Bio. Treatment	- 100% reduction @ 0.4-1.9 ug/L
	o Carbon Ads.	- 100% reduction @ 100 ug/L
	o Resin Ads.	- 100% reduction @ 100 ug/L
Bromomethane	o Stripping	- Air strippable
	o Solvent Ext.	- Soluble in most organics
	o Carbon Ads.	- Adsorbed

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
B. **HALOCARBONS** (Cont'd)		
Carbon Tetrachloride	o Bio. Treatment	- 100% reduction @ 177 ug/L
	o Precip/Coag.	- 51% reduction @ 144 ug/L with alum
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed
Chloroethane	o Stripping	- 90% reduction by air stripping
	o Solvent Ext.	- Extractable with alcohol & aromatics
	o Carbon Ads.	- Adsorbed
Chloroform	o Stripping	- Steam strippable @ 140 mg/L
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed
Chloromethane	o Stripping	- Air strippable
	o Solvent Ext.	- Soluble in most organics
Dibromochloromethane	o Stripping	- Air & steam strippable
	o Solvent Ext.	- Extractable with organics, ether, & alcohols
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed
Dichlorodifluoromethane	o Solvent Ext.	- Extractable with organics, ethers, & alcohols
1,1,-Dichloroethane	o Stripping	- 90% reduction with air stripping
	o Solvent Ext.	- Extractable with alcohols & aromatics
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed
1,2-Dichloroethane	o Bio. Treatment	- Reduced
	o Stripping	- 99% reduction @ 8700 mg/L
	o Solvent Ext.	- 94-100% reduction @ 23-1804 mg/L with kerosene & C_{10}-C_{12} organics
	o Carbon Ads.	- 81% reduction @ 1000 mg/L
	o Resin Ads.	- Adsorbed

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

	CLASS OF CHEMICAL	PROCESS	TREATABILITY
B.	**HALOCARBONS** (Cont'd)		
	1,1-Dichloroethylene	o Stripping	- Air & steam strippable
		o Solvent Ext.	- Extractable with alcohols, aromatics, & ethers
		o Carbon Ads.	- Adsorbed
	1,2-trans-Diethylene	o Stripping	- Air & steam strippable
		o Solvent Ext.	- Extractable with alcohols, aromatics, & ethers
		o Carbon Ads.	- Adsorbed
	1,2-trans-Dichloroethylene	o Stripping	- Air & steam strippable
		o Solvent Ext.	- Soluble in most organics
		o Carbon Ads.	- Adsorbed
	1,2-Dichloropropane	o Stripping	- Air & steam strippable
		o Solvent Ext.	- Soluble in most organics
		o Carbon Ads.	- 93% reduction @ 1000 mg/L
	Hexachlorobutadiene	o Stripping	- Air & steam strippable
		o Solvent Ext.	- Soluble in most organics
		o Carbon Ads.	- 100% reduction @ 100 ug/L
		o Resin Ads.	- 100% reduction @ 100 ug/L
	Hexachlorocyclopentadiene	o Stripping	- Polymerizes with heat
	Hexachloroethane	o Solvent Ext.	- Extractable with aromatics, alcohols, & ethers
		o Carbon Ads.	- 100% reduction @ 100 ug/L
		o Resin Ads.	- 100% reduction @ 100 ug/L
	Methylene Chloride	o Bio. Treatment	- 80-88% reduction @ 10-430 ug/L
		o Carbon Ads.	- 73% reduction @ 190 ug/L
	1,1,2,2-Tetrachloroethane	o Stripping	- Difficult to steam strip
		o Solvent Ext.	- Extractable with aromatics, alcohols, & ethers
		o Carbon Ads.	- Adsorbed
	Tetrachloroethylene	o Stripping	- 90% reduction by air & steam stripping
		o Solvent Ext.	- Soluble in most organics
		o Carbon Ads.	- Adsorbed
		o Resin Ads.	- Adsorbed

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
B. **HALOCARBONS** (Cont'd)		
1,1,1-Trichloroethane	o Bio. Treatment	- >90% reduction @ 8-79 ug/L
	o Stripping	- Air & steam strippable
	o Solvent Ext.	- Extractable with alcohols & aromatics
	o Carbon Ads.	- Adsorbed
	o Resin Ads.	- Adsorbed @ 551 ug/L
1,1,2-Trichloroethane	o Bio. Treatment	- <99% reduction @ 1305 ug/L
	o Stripping	- Air & steam strippable
	o Solvent Ext.	- Extractable with aromatics methanol, & ether
	o Carbon Ads.	- Adsorbed
Trichloroethylene	o Bio. Treatment	- 99% reduction @ 78-214 ug/L
	o Precip/Coag.	- 40% reduction @ 103 ug/L with alum
	o Stripping	- Air & steam strippable
	o Solvent Ext.	- 75% reduction with kerosene & C_{10}-C_{12} solvents
	o Carbon Ads.	- 99% reduction @ 21 ug/L
Trichlorofluoromethane	o Solvent Ext.	- Extractable with alcohols & ethers
	o Carbon Ads.	- Adsorbed
Vinyl Chloride	o Bio. Treatment	- 100% reduction @ 8 ug/L
C. **AROMATICS**		
Acetophenone	o Carbon Ads.	- 50-92% reduction @ 0.1-1000 mg/L - 100% reduction @ 100 ug/L
Benzene	o Bio. Treatment	- 90-100% reduction @ up to 500 mg/L
	o Stripping	- 95-99% reduction
	o Solv. Extraction	- 97% reduction @ 71-290 mg/L
	o Carbon Ads.	- 60-95% reduction @ 1 ug/L to 1500 mg/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
C. **AROMATICS** (Cont'd)		
Chlorobenzene	o Bio. Treatment	- 100% reduction @ 200 mg/L
	o Rev. Osmosis	- 97-100% reduction @ 360 mg/L
	o Stripping	- Steam strippable
	o Solv. Extraction	- 99% reduction with chloroform solvent
	o Carbon Ads.	- 50-95% reduction @ 1-416 mg/L
1,2-Dichlorobenzene	o Stripping	- 70% reduction
1,3-Dichlorobenzene	o Stripping	- 80% reduction
1,4-Dichlorobenzene	o Stripping	- 90% reduction
	o Carbon Ads.	- 60% reduction
2,4-Dinitrotoluene	o Bio. Treatment	- 90-100% reduction @ 0.39-188 mg/L
	o Solv. Extraction	- Extractable
	o Carbon Ads.	- 95% reduction @ 416 mg/L
2,6-Dinitrotoluene	o Solv. Extraction	- Extractable
	o Carbon Ads.	- 95% reduction @ 416 mg/L
Ethylbenzene	o Bio. Treatment	- 90-100% reduction @ 0.192-105 mg/L
	o Precip./Coag.	- 56% reduction @ 153 mg/L with alum
	o Stripping	- 80-93% reduction
	o Solv. Extraction	- 97% reduction
	o Carbon Ads.	- 50-84% reduction @ 1-115 mg/L
Hexachlorobenzene	o Bio. Treatment	- No reduction @ 200 mg/L
	o Rev. Osmosis	- 52% reduction @ 638 mg/L
	o Stripping	- Steam strippable
	o Solv. Extraction	- Extractable
	o Carbon Ads.	- 95% reduction @ 416 mg/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
C. AROMATICS (Cont'd)		
Nitrobenzene	o Bio. Treatment	- Reported to be toxic @ 500 mg/L; 96-100% reduction @ 58-530 ug/L
	o Precip./Coag.	- 34% reduction @ 160 ug/L with alum
	o Stripping	- Steam strippable @ 450-2160 mg/L
	o Solv. Extraction	- Extractable
	o Carbon Ads.	- 95% reduction @ 1-1023 mg/L
Styrene	o Bio. Treatment	- 70-100% reduction
	o Stripping	- 98-99% reduction
	o Solv. Extraction	- >93% reduction
	o Carbon Ads.	- 55-97% reduction @ 20-200 mg/L
Toluene	o Bio. Treatment	- 48-100% reduction @ 8 ug/L to 500 mg/L; 500 mg/L was inhibitory
	o Stripping	- 73-92% reduction
	o Solv. Extraction	- 94-96% reduction @ 41-44 mg/L
	o Carbon Ads.	- 79-98% reduction @ 0.12-317 mg/L
1,2,4-Trichlorobenzene	o Bio. Treatment	- 100% reduction @ 200 mg/L
Xylene	o Bio. Treatment	- 92-95% reduction @ 20-200 ug/L
	o Solv. Extraction	- >97% reduction
	o Carbon Ads.	- 68-99% reduction @ 0.14-200 mg/L
D. PHENOLS		
4-Chloro-3-Methylphenol	o Bio. Treatment	- Toxic @ 50-100 mg/L Inhibitory but slowly degradable @ <50 mg/L
	o Solv. Extraction	- Extractable with benzene, alcohol, & nitrobenzene
	o Carbon Ads.	- 100% reduction @ 100 ug/L
	o Resin Ads.	- 100% reduction @ 100 ug/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
D. **PHENOLS** (Cont'd)		
2-Chlorophenol	o Bio. Treatment	- 90-95% reduction @ 150-200 mg/L
	o Rev. Osmosis	- 66% reduction
	o Solv. Extraction	- Extractable with diisopropylether, benzene, butylacetate, & nitrobenzene
m-Cresol	o Bio. Treatment	- 96% reduction
	o Solv. Extraction	- 91% reduction @ 291 mg/L
o-Cresol	o Bio. Treatment	- 95% reduction
	o Solv. Extraction	- 90-99% reduction @ 307-890 mg/L
p-Cresol	o Bio. Treatment	- 96% reduction
	o Solv. Extraction	- 91% reduction @ 291 mg/L
2,4-Dichlorophenol	o Bio. Treatment	- 98-100% reduction @ 60-200 ug/L
	o Resin Ads.	- 100% reduction @ 430 mg/L
	o Misc. Sorbents	- Extractable with benzene, alcohol, & nitrobenzene
2,4-Dimethylphenol	o Bio. Treatment	- 94% reduction
	o Solv. Extraction	- Extractable with benzene & alcohol
4,6-Dinitro-2-Methylphenol	o Solv. Extraction	- Extractable with benzene & acetone
2,4-Dinitrophenol	o Bio. Treatment	- 85% reduction
	o Solv. Extraction	- Extractable with benzene & alcohol
	o Carbon Ads.	- Adsorbed
2-Nitrophenol	o Solv. Extraction	- Extractable with benzene & Alcohol
4-Nitrophenol	o Rev. Osmosis	- Removable
	o Solv. Extraction	- Extractable with benzene & Alcohol

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

	CLASS OF CHEMICAL	PROCESS	TREATABILITY
E.	**PHENOLS** (Cont'd)		
	Pentachlorophenol	o Bio. Treatment	- 26% reduction @ 200 mg/L
		o Solv. Extraction	- Extractable with benzene, alcohol & nitrobenzene
		o Carbon Ads.	- 100% reduction @ 10 mg/L
		o Resin Ads.	- 100% reduction @ 100 ug/L
	Phenol	o Bio. Treatment	- 62-100% reduction @ 5-500 mg/L; reported to be inhibitory @ 500 mg/L
	2,4,6-Trichlorophenol	o Bio. Treatment	- 100% reduction @ 20-200 mg/L; reported to be inhibitory @ 50-200 mg/L
		o Solv. Extraction	- Extractable with benzene, alcohol, nitrobenzene
		o Carbon Ads.	- 100% reduction @ 100 ug/L
		o Resin Ads.	- 100% reduction @ 0.1-510 mg/L
E.	**PESTICIDES**		
	Aldrin	o Bio. Treatment	- Not significantly degraded
		o Rev. Osmosis	- 100% reduction
		o Carbon Ads.	- 98-100% reduction @ 8-100 ug/L
		o Resin Ads.	- 100% reduction @ 100 ug/L
	Chlordane	o Bio. Treatment	- Slightly degraded
		o Carbon Ads.	- 97-100% reduction @ 13-1430 ug/L
	DDD	o Carbon Ads.	- 99.8% reduction @ 56 ug/L
	DDE	o Rev. Osmosis	- 100% reduction
		o Carbon Ads.	- >97% reduction @ 38 ug/L
	DDT	o Bio. Treatment	- Not significantly degraded
		o Precip./Coag.	- 98% reduction @ 10 ug/L with alum coagulant
		o Rev. Osmosis	- 100% reduction

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
E. **PESTICIDES** (Cont'd)		
DDT (Cont'd)	o Carbon Ads.	- >99% reduction @ 10-100 ug/L
	o Resin Ads.	- 100% reduction @ 100 ug/L
Dieldrin	o Bio. Treatment	- Not significantly degraded
	o Precip./Coag.	- 55% reduction @ 10 ug/L with alum coagulant
	o Rev. Osmosis	- 100% reduction
	o Carbon Ads.	- 75-100% reduction @ 19-60 ug/L
Endrin	o Bio. Treatment	- Not significantly degraded
	o Precip./Coag.	- 35% reduction @ 10 ug/L with alum coagulant
	o Carbon Ads.	- 80-99% reduction @ 10-62 ug/L
Heptachlor	o Bio. Treatment	- Slightly degraded @ 500 mg/L
	o Rev. Osmosis	- 100% reduction
	o Carbon Ads.	- >99% reduction @ 6-80 ug/L
Heptachlor-epoxide	o Rev. Osmosis	- 99.8% reduction
Lindane	o Bio. Treatment	- Not significantly degraded
	o Precip./Coag.	- <10% reduction @ 10 ug/L with alum coagulant
	o Rev. Osmosis	- >99% reduction
	o Solv. Extraction	- 30->99% reduction @ 10 ug/L
Toxaphene	o Carbon Ads.	- 97-99% reduction @ 36-155 ug/L
	o Resin Ads.	- >99% reduction @ 70-2600 ug/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
F. **POLYNUCLEAR AROMATICS**		
Acenaphthalene	o Resin Ads.	- 100% reduction @ 100 ug/L
Acenaphthene	o Precip./Coag.	- Precipitated with alum
Anthracene	o Bio. Treatment	- Toxic @ 500 mg/L
	o Solv. Extraction	- Extractable with toluene
Benzanthracene	o Bio. Treatment	- Slowly oxidized @ 500 mg/L
	o Precip./Coag.	- Separable by gravity or sand filtration
11,12-Benzofluoranthene	o Precip./Coag.	- Separable by gravity or sand filtration
1,12-Benzoperylene	o Precip./Coag.	- Separable by gravity or sand filtration
Benzo(a)-pyrene	o Precip./Coag.	- Separable by gravity or sand filtration
2-Chloronapthalene	o Precip./Coag.	- Precipitated with alum
Chrysene	o Precip./Coag.	- Separable by gravity & sand filtration
Napthalene	o Bio. Treatment	- 85-95% reduction; Inhibitory @ 500 mg/L
	o Precip./Coag.	- Separable by gravity or sand filtration
Napthalene (Cont'd)	o Stripping	- Air strippable by 50:1 volume of air
	o Carbon Ads.	- 70% reduction
Phenanthrene	o Carbon Ads.	- 80% reduction @ 100 ug/L
	o Resin Ads.	- 100% reduction @ 100 ug/L
Pyrene	o Precip./Coag.	- Separable by gravity or sand filtration
	o Carbon Ads.	- 80% reduction @ 100 ug/L
	o Resin Ads.	- 100% reduction @ 100 ug/L

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY
G. **NON-HALOGENATED ALIPHATICS**		
Acetone	o Bio. Treatment	- 50-100% reduction
	o Rev. Osmosis	- 15-100% reduction @ 1000 mg/L - dependent upon membrane
	o Carbon Ads.	- 22% reduction @ 1000 mg/L
Acrolein	o Solv. Extraction	- Extractable with xylene
	o Carbon Ads.	- 30% reduction @ 1000 mg/L
Acrylonitrile	o Bio. Treatment	- 70-100% reduction
	o Stripping	- Could be flash evaporated
	o Solv. Extraction	- Extractable with ethyl ether
Ethylene Glycol	o Bio. Treatment	- 97% reduction
	o Carbon Ads.	- 7% reduction @ 1000 mg/L
Formaldehyde	o Bio. Treatment	- Conflicting data; removable & inhibitory @ 720-3000 mg/L
	o Rev. Osmosis	- <20-80% reduction @ 1000 mg/L dependent upon membrane
	o Carbon Ads.	- 9% reduction @ 1000 mg/L
Glycerine	o Bio. Treatment	- Readily oxidized @ 720 mg/L
Methyl Ethyl Ketone	o Solv. Extraction	- 69-88% reduction @ 12,200 mg/L
	o Carbon Ads.	- 47% reduction @ 1000 mg/L
Propylene Glycol	o Carbon Ads.	- 12% reduction @ 1000 mg/L
Glycol	o Carbon Ads.	- 52% reduction @ 1000 mg/L
H. **PHTHALATES**		
Bis(2-Ethylhexyl) Phthalate	o Bio. Treatment	- 70-78% reduction @ 5 mg/L
	o Precip./Coag.	- 80-90% reduction @ 0.5-3.5 ug/L with aluminum sulphate coagulant
	o Solv. Extraction	- Extractable with ethyl ether and benzene

TABLE B-1(1)
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY	REFEREN
H. **PHTHALATES** (Cont'd)			
Bis)2-Ethylhexyl) Phthlatate (Cont'd)	o Carbon Ads.	- >98% reduction @ 1300 ug/L	
Butylbenzyl Phthalate	o Bio. Treatment	- Biodegradable	
	o Solv. Extraction	- Extractable with ethyl ether & benzene	
Di-N-Butyl Phthalate	o Bio. Treatment	- Biodegradable @ 200 mg/L	
	o Precip./Coag.	- 60-70% reduction @ 2.5-4.5 ug/L with aluminum sulphate	
	o Solv. Extraction	- Extractable with ethyl ether & benzene	
Diethyl Phthalate	o Precip./Coag.	- Biodegradable	
	o Solv. Extraction	- Extractable with ethyl ether & benzene	
Dimethyl Phthalate	o Bio. Treatment	- Degradable; 100% reduction @ 215 ug/L	
	o Precip./Coag.	- 15% reduction @ 183 ug/L with alum	
	o Solv. Extraction	- Extractable with ethyl ether & benzene	
	o Carbon Ads.	- 100% reduction @ 100 ug/L	
	o Resin Ads.	- 100% reduction @ 100 ug/L	
I. **AMINES**			
Benzidine	o Bio. Treatment	- Inhibitory @ 500 mg/L; not reduced @ 1.6 ug/L	
	o Carbon Ads.	- Adsorbed	
Dimethylnitrosamine	o Carbon Ads.	- Not adsorbed	
Di-N-Propylamine	o Carbon Ads.	- 80% reduction @ 1000 mg/L	
J. **ALCOHOLS**			
n-Amyl Alcohol (1-Pentanol)	o Bio. Treatment	- toxic @ >350 mg/L	
	o Carbon Ads.	- 72% reduction @ 1000 mg/L	

TABLE B-1[1]
CHEMICAL TREATABILITY SUMMARY

CLASS OF CHEMICAL	PROCESS	TREATABILITY	REFEREN
J. **ALCOHOLS** (Cont'd)			
Ethanol	o Bio. Treatment	- 70-100% reduction @ up to 1000 mg/L	
	o Rev. Osmosis	- <20-100% reduction @ 1000 mg/L - dependent upon membrane	
	o Solv. Extraction	- 7% reduction @ 286 mg/L	
	o Carbon Ads.	- 10% reduction @ 1000 mg/L	
Isobutanol	o Carbon Ads.	- 42% reduction @ 1000 ug/L	
Isopropanol	o Bio. Treatment	- 70-100% reduction	
	o Carbon Ads.	- 13% reduction @ 1000 ug/L	
Methanol	o Bio. Treatment	- 30-85% reduction	
	o Rev. Osmosis	- 0-40% reduction @ 1000 mg/L - dependent upon membrane	
	o Carbon Ads.	- 4-33% reduction @ 15-1000 mg/L	

ABBREVIATIONS

Bio. Treatment	Biological Treatment
Carbon Ads.	Activated Carbon Adsorption
Misc. Sorbents	Miscellaneous Sorbents
Precip/Coag.	Precipitation/Coagulation
Resin Ads.	Resin Adsorption
Rev. Osmosis	Reverse Osmosis
Solv. Extraction	Solvent Extraction
Solvent Ext.	Solvent Extraction
Ultra Filt.	Ultra Filtration

APPENDIX C

METHODOLOGY FOR EVAPORATOR EMISSIONS ESTIMATE

METHODOLOGY FOR EVAPORATOR EMISSIONS ESTIMATE

The following sections outline the methodology used to obtain the values presented in each of the six columns shown in Table 25 (p. 210).

Column 1

The average expected contaminant concentrations in the influent to the physical/chemical plant have been calculated using OWMC's waste profile data along with data from the USEPA Treatability Manual (Ref: USEPA[38]) as follows:

- Industry categories contained in the USEPA Treatability Manual (UESPA[38]) were collated with OWMC's waste quantity data using the SIC numbers which are common to both these documents. This enabled estimated waste quantities to be obtained for each of the various industrial categories given in the USEPA Treatability Manual.

- The USEPA Treatability Manual provides data on the frequency of occurrence of specific contaminants in raw wastewater from a broad range of different industry groups and also gives detected minimum, mean and maximum contaminant concentrations. These data were used to calculate the estimated total average quantity waste which is expected to contain each of the twenty contaminants of concern and a weighted average concentration for each contaminant (Column 1).

Column 2

The values summarized in Column 2 represent the maximum detected concentrations for each contaminant. These data were obtained from USEPA[35].

Column 3

The expected average quantities of waste containing each contaminant were obtained by two methods. First, a rough estimate was obtained using data on waste quantities and contaminant frequency of occurrence as discussed above under "Column 1". These calculated values (expressed as a percentage of the total expected quantity of inorganic waste) were compared with data from WPCF[39] on the percentage occurrence of organic priority pollutants in industrial effluents in order to arrive at the best estimates presented in Column 3.

Column 4

The values in Column 4 were calculated from treatability data available in the literature (see references) for these unit operations which are included in the proposed physical/chemical treatment plant design. The values shown in Column 4 represent best estimate of the cumulative effects of primary and secondary treatment processes such as sedimentation, chemical precipitation, coagulation, air flotation and filtration in removing the initial contaminant concentrations summarized in Column 1.

Column 5

Column 5 data represent best estimates of the likely cumulative effects of activated carbon and reverse osmosis on contaminant concentrations from Column 4, again using treatability data available from the literature (see references).

Column 6

The values given in Column 6 represent estimated average contaminant discharge rates from the evaporator based on 8400 evaporator operating hours per year.

For the inorganic contaminants of concern it has been assumed that the main mechanisms by which inorganics are likely to escape from the evaporator into the air is by entrainment of water droplets in the evaporator plume. Data from suppliers of evaporation equipment indicates that the concentration of water droplets in the evaporator plume after demisting will be approximately 25 ppm. This value has therefore been used as a basis for calculating the values in Column 6 for the four inorganic contaminants of concern.